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NASA CR 159824

BAT Report No. D2536-941003

(NASA-CR-159824) NASTRAN LEVEL 16 USER'S
MANUAL UPDATES FOR AEROELASTIC ANALYSIS OF
BLADED DISCS (Textron Bell Aerospace Co.,
Buffalo, N. Y.) 167 p HC A08/MF A01

N81-19481

Unclassified
CSCL 20K G3/39 18072

**NASTRAN LEVEL 16 USER'S MANUAL UPDATES
FOR AEROELASTIC ANALYSIS OF BLADED DISCS**

by

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A. M. GALLO



**BELL AEROSPACE TEXTRON
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-20382

**NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO**

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INTRODUCTION

A computer program based on state-of-the-art compressor and structural technologies applied to bladed shrouded discs has been developed and made operational in NASTRAN Level 16.

The problems encompassed include aeroelastic analyses, modes and flutter.

The program is documented in the form of five NASA Contractor's Reports — one Technical Report and four Updates to NASTRAN Level 16 Theoretical, User's, Programmer's and Demonstration manuals. This report describes the User's manual updates.

USER'S MANUAL UPDATES

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USER'S MANUAL UPDATES

STRUCTURAL MODELING

**1.15 STATIC AEROELASTIC AND FLUTTER MODELING OF AXIAL FLOW
TURBOMACHINES**

1.15.1 Introduction

The NASTRAN aeroelastic and flutter capability has been extended to solve a class of problems associated with axial flow turbomachines. The capabilities included are:

1. Steady state aerothermoelastic analysis of compressors to determine:

(a) The change in geometry between the design point operating shape and the "as manufactured" shape of the flexible blade to ensure the required performance (pressure ratio, flow rate, rpm) at the design point. (This is termed the "design" problem.)

(b) The performance at off-design operating conditions for a given "as manufactured" blade shape. (This is termed the "analysis" problem.)

(c) Displacements, stresses, reactions, plots, etc., at selected operating points over the compressor map.

(d) A differential stiffness matrix due to centrifugal and aerodynamic pressure and thermal loads for use in subsequent modal analysis.

2. Modal, unstalled flutter and subcritical roots analysis of compressors and turbines.

The rotor/stator of a single-stage, or each stage of a multi-stage compressor or turbine is analyzed as an isolated structure. Two new Rigid Formats (Displacement RF 16 and Aero RF 9) have been developed, one each for the aeroelastic steady state and the oscillatory state problems (see Sections 3.21, 3.22, 3.23). The rotational cyclic symmetry (see Section 1.12) inherent in these structures about the axis of rotation has been taken into account in designing the capability, so that only a representative one-blade sector need be idealized.

The steady aerothermoelastic analysis is based on the theory described in Volume I of Reference 1. The computer code of the same reference (Volume II), with minor changes, has been adapted for NASTRAN in the functional module ALG. The current NASTRAN Static Analysis with Differential Stiffness Rigid Format has been accordingly modified to include the effect of centrifugal, aerodynamic pressure and temperature loads.

The existing features of NASTRAN for Normal Modes Analysis using Cyclic Symmetry (Section 3.16) and Modal Flutter Analysis (Section 3.20) have been suitably combined for the modal flutter and subcritical roots analysis of the axial flow turbomachinery rotor/stator.

These developments are compatible with the general structural capability in NASTRAN. The structural part of the problem is modeled as described in Section 1 of the User's Manual. This section deals with the aerodynamic data pertaining to the bladed disc sector. The associated aerodynamic modeling is discussed in Section 1.15.2.

Section 1.15.3 describes the steady aerothermo-
elastic "design/analysis" formulations.

Section 1.15.5 presents the modal, flutter and
subcritical roots analyses.

Sample problems and their solutions are presented
in Sections 1.15.4 and 1.15.6.

1.15.2 Aerodynamic Modeling

The aerodynamic model is based on a grid generated by the intersection of a series of streamlines and "computing stations" (similar to potential lines) as shown in Figure 1. This arrangement also facilitates the subsequent use of two-dimensional, unsteady, subsonic and supersonic infinite cascade theories (see Section 1.15.3 of the Theoretical Manual) in the flutter problem. They are used in a strip-theory manner on the various streamlines spanning the blade.

The aerodynamic loads are assumed significant only on the bladed portion of a bladed disc and no other part of the structure need be modeled aerodynamically. The data required to generate the aerodynamic model for the steady state aeroelastic analyses are specified on DTI bulk data cards, and are described in Section 1.15.3.1 of the User's Manual. Blade streamline data for flutter and subcritical roots analyses are specified on STREAMLi bulk data cards.

The streamlines are defined by the intersection of the blade mean surface and a set of coaxial cylindrical (or conical) surfaces. The axis of the cylinders (cones) coincides with the axis of rotation of the turbomachine. The "computing stations" lie on the blade mean surface and divide it from the leading edge to the trailing edge. The choice of the number and location of the streamlines and the "computing stations" is dictated by the expected variation of the relative flow properties across the blade span, and the complexity of the mode shapes exhibited by this part of the structure. However, a minimum of three streamlines (including the blade root and

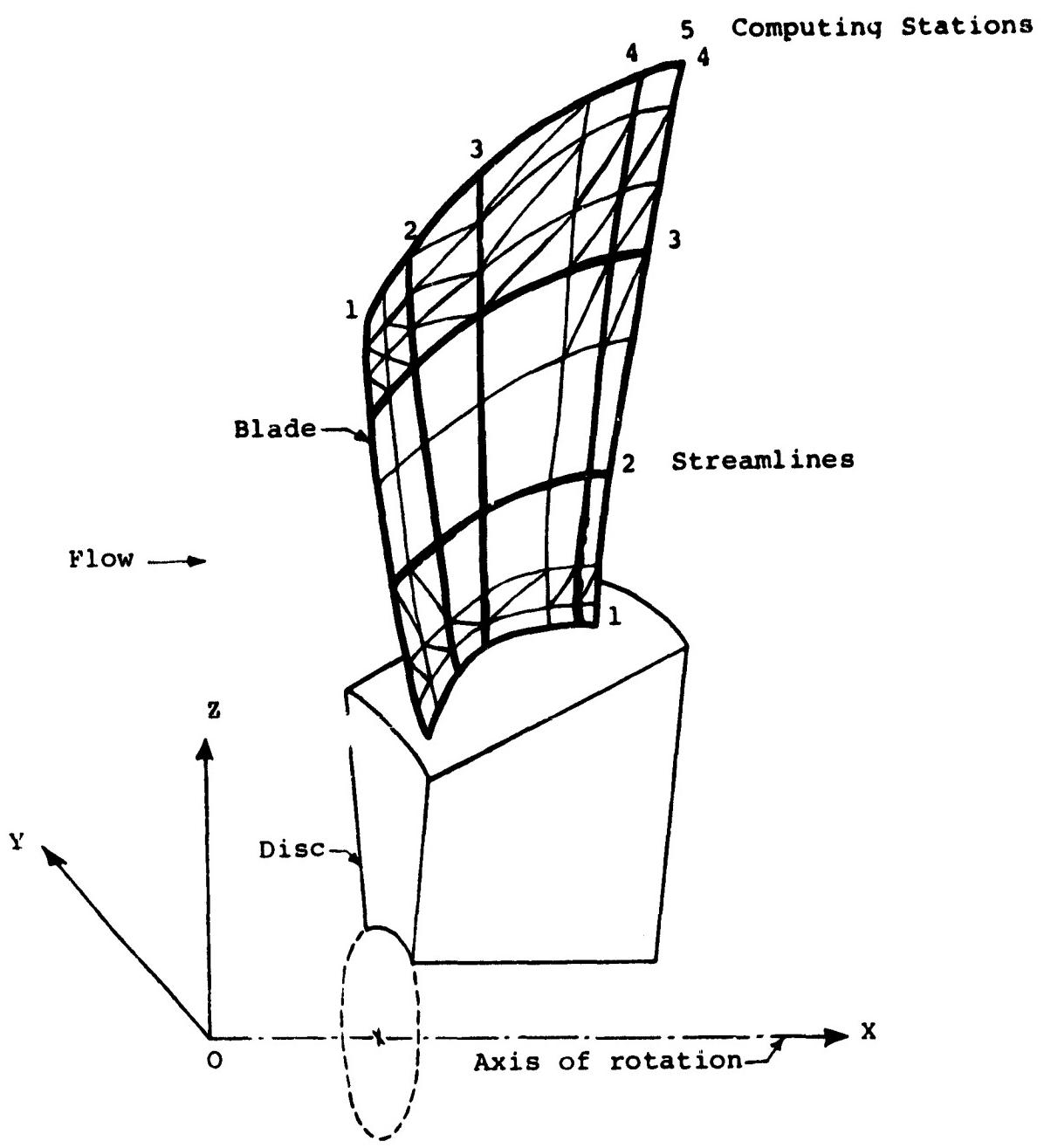


Figure 1 Bladed-disc Aerodynamic Grid And The Basic Coordinate System

the tip) and three "computing stations" (including the blade leading edge and the trailing edge) must be specified.

The distribution of the aerodynamic parameters over the blade is, in general, different from that of the structural parameters such as stress, strain, etc. Accordingly, the aerodynamic model and the structural model of the blade, in general, may differ. The difference currently permitted in the two models is as seen in Figure 1 wherein the aerodynamic grid is shown to be a part of the structural grid.

The x-axis of the BASIC coordinate system (Figure 1) is chosen to coincide with the axis of rotation and is oriented in the direction of the flow. The location of the origin is arbitrary. The z-plane (BASIC) lies normal to the "mean" meridional plane passing through the blade, with the z-axis (BASIC) directed towards the blade. The aerodynamic grid can be specified in any coordinate system (CP). The aerodynamic model data mainly related to the bladed disc problems are specified on the DTI, STREAML1 and STREAML2 bulk data cards.

1.15.3 Steady Aerothermoelastic "Design/Analysis"

An operating point on a compressor map defines a distribution of centrifugal force and aerodynamic pressure and temperature loads on the bladed-disc of the axial flow turbomachine. The equilibrium, deformed shape of the elastic structure is reached at the end of a series of quasi-equilibrium states during which the loads on the bladed-disc and its geometric stiffness change as a function of the deformation. The operating point pressure ratio (given the flow rate and the rpm), in effect, also changes during this process.

Two different problems can thus be stated:

1. Given the desired design operating point and the "rigid" geometry, to determine the "as manufactured" geometry ("design" problem) that would produce the design conditions and
2. Given the "as manufactured" geometry, to determine the performance of the flexible blade at off-design operating points ("analysis" problem).

Rigid format Displacement 16 has been developed to solve these "design/analysis" problems. The value of the PARAMETER SIGN (= +1) selects the analysis or the design mode of the rigid format. Deformation of the structure as a result of the applied centrifugal and aerodynamic loads is used to revise the blade geometry each time through the differential stiffness loop of the rigid format. Because of the non-linear relationship between the blade geometry and the resulting operating point pressure ratio, provision is made to control the fraction of the displacements used to redefine the blade geometry. This is especially helpful in the solution of the

"design" problem. The fractions of the displacements used to redefine the blade geometry are specified via the FXCOOR, FYCOOR and FZCOOR parameters. The application of the aerodynamic pressure and thermal loads is controlled respectively by the parameters APRESS and ATEMP. These parameters also enable the inclusion of the centrifugal loads alone.

The functional module ALG is used in the rigid format before, within and after the differential stiffness loops (see Section) to generate the aerodynamic loads. Printed output from this module during these three stages can respectively be controlled through the use of the parameters IPRTCI, IPRTCL and IPRTCF. This enables observation of the variation in the aerodynamic loads as a function of the blade geometry.

GRID, CTRIA2 and PTRIA2 bulk data cards for the final blade shape can be punched out using the parameter PGEØM. At the end of a "design" run, these define the "as manufactured" blade shape which can subsequently be "analyzed" at selected operating points over the compressor map. In an "analysis" run at any operating point, the total stiffness (elastic and geometric) of the bladed-disc structure can be saved via the parameter KTØUT for use in subsequent modal, modal flutter and subcritical roots analyses.

The subsections 1.15.3.1 and 1.15.3.2 describe the aerodynamic Direct Table Input and the output data for the steady state analyses.

1.15.3.1 Aerodynamic DTI Data

The input data consist of an initial indication of the number of entries that are to be made to each of the two program sections (analytic meanline blade section and aerodynamic section), and then a data-set for each entry to each section. The data that are required for the interfacing of the output from the analytic meanline blade section to the aerodynamic section are included in the data-set for the analytic meanline section. Because partial input to the aerodynamic section is generated by execution of the analytic meanline section, the input for the aerodynamic section to be supplied directly by the user varies. This is indicated in the charts below by giving the variable name LOG5 for the file from which any data are taken that are not always supplied directly.

LOG5 is the file from which input is taken that is generated by the analytic meanline section. When the analytic meanline section has been directed to produce data for the aerodynamic section for a particular computing station, LOG5 becomes an internally generated scratchfile. Otherwise, LOG5 is attached to the standard input unit and the user supplies the data.

The following input data items must be input using NASTRAN Direct Table Input (DTI) bulk data cards. A description of the DTI card is in the NASTRAN User's Manual on page 2.4-105. The table data block name must be ALGDB. The trailer value for T1 is the number of logical records in the DTI table, not

counting the header record. This is the same as the maximum value of IREC used in the table. The trailer values for T2 through T6 are all zero. Each of the following input cards corresponds to one logical record of the DTI table.

Trailing zeroes need not be input. Data types, i.e., alphanumeric (BCD), real and integer, must correspond to those specified for each data item. Data item names that begin with the letters I,J,K,L,M, and N are to be input as integers while all others are input as real numbers. Titles are input as alphanumeric (BCD) with the restriction that only alphabetic letters occupy the first character in each field of the DTI card. Titles may use up to nine DTI fields.

In the following chart, one line, which may be continued, corresponds to one logical record of a DTI card.

TITLE1

NANAL NAERO

The following data-set is input to the analytic meanline section, and will occur NANAL times.

The last record in this set is indicated with an asterisk.

TITLE2

NLINES NSTNS NZ NSPEC NPOINT NBLADE ISTAK

(cont.) IPUNCH ISECN IFCORD IFPLOT IPRINT ISPLIT INAST

(cont.) IRLE IRTE NSIGN

ZINNER ZOUTER SCALE STACKX PLTSZE

KPTS IFANGS

XSTA RSTA - Occurs KPTS times

R BLAFOR - Occurs NLINES times

Occurs
NSTNS
Times

ZR B1 B2 PP QQ RLE

TC TE Z CORD DELX DELY

Occurs
NSPEC
Times

S BS - Only if ISECN = 1 or 3

NRAD NDPTS NDATR NSWITC NLE NTE

XKSHPE SPEED

NOUT1 NOUT2 NOUT3 - Refers to leading
edge station

NR NTERP NMACH NLOSS NL1

(cont.) NL2 NEVAL NCURVE NLITER NDEL

(cont.) NOUT1 NOUT2 NOUT3 NBLAD

R XLOSS - Occurs NR times

Occurs
for each
station
within
blade or
at trailing
edge

This group
is used to
generate
LOG5 data
for the
aerodynamic
section

RTE

DM DVFRAC] -Occurs NDPTS times

Occurs
NRAD
times

* RDTE DELTAD AC-Occurs NDATR times

The following data-set is input to the aerodynamic
section and the last record in this set is indicated
with a double asterisk.

TITLE3

CP GASR G EJ

NSTNS NSTRMS NMAX NFORCE NBL NCASE

(cont.) NSPLIT NSET1 NSET2 NREAD NPUNCH NPLOT

(cont.) NPAGE NTRANS NMIX NMANY NSTPLT NEQN NLE NTE NSIGN

NWHICH - Occurs NMANY times on the same card

G EJ SCLFAC TOLNCE VISK SHAPE

XSCALE PSCALE RLOW PLOW XMMAX RCONST

CONTR CONMX

FLOW SPDFAC

NSPEC

XSTN RSTN - Occurs NSPEC times

Occurs
NSTNS
Times

NDATA NTERP NDIMEN NMACH
 DATAAC DATA1 DATA2 DATA3 - Occurs
 NDATA times] Inlet condition specification

(LOG5) NDATA NTERP NDIMEN NMACH NWORK
 (cont.) NLOSE NL1 NL2 NEVAL NCURVE NLITER
 (cont.) NDEL NOUT1 NOUT2 NOUT3 NBLADE
 (LOG5) SPEED-IF NDATA > 0
 (LOG5) DATAAC DATA1 DATA2 DATA3 DATA4] Occurs NDATA times
 (cont.) DATA5
 (LOG5) DATA6 DATA7 DATA8 DATA9] DELC DELTA - Occurs NDEL times

WBLOCK BBLOCK BDIST -Occurs NSTNS times

NDIF] Occurs NSET1 times
 DIFF FDHUB FDMID FDTIP -Occurs NDIFF times

NM NRAD] Occurs NSET2 Times.
 TERAD
 DM WFRAC -Occurs NM times

DELF(1) DELF(2)....DELF (NSTRMS) - if NSPLIT = 1
 or NREAD = 1

** R X XL II JJ - Occurs NSTRMS times for NSTNS stations
 if NREAD = 1

For stations 2 thru NSTNS

Data Item Definitions:

The aerodynamic section may be used with any self-consistent unit system and, additionally, a "linear dimension scaling factor" (SCLFAC) is incorporated into the input so that some commonly used but inconsistent unit systems may be used. This is principally intended to allow the use of inches for physical dimensions and yet retain feet for velocities. The basic dimensions used in the data are length (L), time (T), and force (F). Angles are expressed in degrees (A), and temperatures on an absolute temperature scale (D). Heat capacities (H) are also required. Some possible unit systems are given below, together with the corresponding value of SCLFAC.

L	T	F	D	H	SCLFAC
Feet	Seconds	Pounds	Deg. Rankine	BTU	1.0
Inches	Seconds	Pounds	Deg. Rankine	BTU	12.0
Meters	Seconds	Kilograms	Deg. Kelvin	CHU	1.0

Note that some data names are used in more than one section; care should be taken to consult the correct sub-division below for definitions.

a. Initial Directives

TITLE1 This is a title card for the run.
NANAL Set NANAL = 1
NAERO Set NAERO = 1

b. Analytic Meanline Blade Section

For a more detailed discussion of the input to this section through item XB, see Reference and . For this section, the dimensioned input is either in degree (A) or in length (L).

TITLE2	A title card for the analytic meanline section of the program.
NLINES	The number of stream surfaces which are defined, and on which blade sections will be designed. Must satisfy $2 \leq NLINES \leq 21$.
NSTNS	The number of computing stations at which the stream surface radii are specified. Must satisfy $3 \leq NSTNS \leq 10$.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq NZ \leq 15$.
NSPEC	The number of radially disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq NSPEC \leq 21$.
NPOINT	The number of points that will be generated to specify the pressure and suction surfaces of each blade section. Must satisfy $2 \leq NPOINT \leq 80$. Generally, no less than 30 should be used.
NBLADE	The number of blades in the blade row.
ISTAK	If ISTAK = 0, the blade will be stacked at the leading edge. If ISTAK = 1, the blade will be stacked at the trailing edge.

If ISTAK = 2, the blade will be stacked at,
or offset from, the section centroid.

IPUNCH Set IPUNCH = 0

ISECN If ISECN = 0, the blade will be constructed
using the polynomial camber line and the
standard (i.e., double-cubic) thickness
distribution.
If ISECN = 1, the exponential camber
line and the standard thickness distribution
will be used.
If ISECN = 2, the circular arc camber line
and the double-circular-arc thickness
distribution will be used.
If ISECN = 3, the multiple-circular-arc
meanline and the standard thickness
distribution will be used.

IFCORD If IFCORD = 0, the meridional projection
of the stream surface blade section chords
are specified.
If IFCORD = 1, the stream surface blade
section chords are specified.

IFPLOT Set IFPLOT = 0

IPRINT The input data is always listed by the
program. Details of the stream surface
and manufacturing sections are printed
as prescribed by IPRINT.

If IPRINT = 0, details of the stream surface and manufacturing sections are printed.

If IPRINT = 1, details of stream surface sections are printed.

If IPRINT = 2, details of manufacturing sections are printed.

If IPRINT = 3, details of neither stream surface nor manufacturing sections are printed. (The interface data for use with the aerodynamic section of the program is still displayed.)

ISPLIT	Set ISPLIT = 0
INAST	Set INAST = 0. See the Output Data description (Section) for further details.
IRLE	The computing station number at the blade leading edge.
IRTE	The computing station number at the blade trailing edge.
NSIGN	Indicator used to sign blade pressure forces according to program sign conventions. For <u>compressor rotors</u> , if the machine rotates clockwise when viewed from the front, set NSIGN to 1; otherwise, set NSIGN to -1. For <u>compressor stators</u> , the two values given for NSIGN are reversed.

ZINNER, ZOUTER The NZ manufacturing sections are equi-spaced between z equals ZINNER and ZOUTER.

SCALE Set scale = 0.0.

STACKX This is the axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.

PLTSZE Set PLTSZE = 0.0.

KPTS The number of points provided to specify the shape of a computing station.
If KPTS = 1, the computing station is upright and linear.
If KPTS = 2, the computing station is linear and either upright or inclined.
If KPTS > 2, a spline curve is fit through the points provided to specify the shape of the station.

IFANGS If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station.
If IFANGS = 1, these calculations will be performed at that station.

XSTA An array of KPTS axial coordinates (relative to an arbitrary origin) which, together with RSTA, specify the shape of a particular computing station.

RSTA An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.

R The stream surface radii at NLINE locations at each of the NSTNS stations.

BLAFOR Set BLAFOR = 0.0.

ZR The variation of properties of the stream surface blade section is specified as a function of stream surface number. The various quantities are then interpolated (or extrapolated) at each stream surface. The stream surfaces are numbered consecutively from the inner-most outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.

B1 The blade inlet angle.

B2 The blade outlet angle.

PP If ISECN = 0, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value. Must satisfy $-2.0 < PP < 1.0$.
If ISECN = 1, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value forward of the inflection point. Must satisfy $0.0 < PP < 1.0$.

If ISECN = 2 or 3, PP is superfluous.

QQ If ISECN = 0, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value. Must satisfy $0.0 \leq QQ \leq 1.0$.
If ISECN = 1, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value rearward of the inflection point. Must satisfy $0.0 < QQ \leq 1.0$.
If ISECN = 2 or 3, QQ is superfluous.

RLE The ratio of blade leading edge radius to chord.

TC The ratio of blade maximum thickness to chord.

TE The ratio of blade trailing edge half-thickness to chord.
If ISECN = 2, TE is superfluous.

Z The location of the blade maximum thickness, as a fraction of camber line length from the leading edge.
If ISECN = 2, Z is superfluous.

CORD If IFCORD = 3, CORD is the meridional projection of the blade chord.
If IFCORD = 1, CORD is the blade chord.

DELX,
DELY The stacking axis passes through the stream surface blade sections, offset from the centroids, leading, or trailing edge by DELX

and DELY in the x and y directions respectively.

S, BS If ISECN = 1 or 3, S and BS are used to specify the locations of the inflection point (as a fraction of the meridionally-projected chord length) and the change in camber angle from the leading edge to the inflection point. If the absolute value of the angle at the inflection point is larger than the absolute value of Bl, BS should have the same sign as Bl, otherwise, Bl and BS should be of opposite signs.

NRAD The number of radii at which a distribution of the fraction of trailing edge deviation is input. Must satisfy $1 \leq NRA.D \leq 5$.

NDPTS The number of points used to define each deviation curve. Must satisfy $1 \leq NDPTS \leq 11$.

NDATR The number of radii at which an additional deviation angle increment and the point of maximum camber are specified. Must satisfy $1 \leq NDATR \leq 21$.

NSWITC If NSWITC = 1, the deviation correlation parameter "m" for the NACA (A_{10}) meanline is used.

If NSWITC = 2, the deviation correlation parameter "m" for double-circular-arc blades is used.

NLE Station number at leading edge.

NTE Station number at trailing edge.

XKSHPE The blade shape correction factor in the deviation rule.

SPEED	See definition for Aerodynamic Section.
NR	The number of radii where a "loss" is input.
NTERP	
NMACH	
NLOSS	
NL1	
NL2	
NEVAL	
NCURVE	See definition for Aerodynamic Section.
NLITER	
NDEL	
NOUT1	
NOUT2	
NOUT3	
NBLAD	
R	Radius at which loss is specified.
XLOSS	Loss description. The form is prescribed by NLOSS; see aerodynamic section.
RTE	Radius at blade trailing edge where the following deviation fraction/chord curve applies. If NRAD = 1, it has no significance. Must increase monotonically.
DM	The location on the meridional chord where the deviation fraction is given. Expressed as a fraction of the meridional chord from the leading edge. Must increase monotonically.
DVFRAC	Fraction of trailing -edge deviation that occurs at location DM.
RDTE	Radius at trailing edge where additional deviation and point of maximum camber are specified.

DELTAD	Additional deviation angle added to that determined by deviation rule. Input positive for conventionally positive deviation for both rotors and stators.
AC	Fraction of blade chord from leading edge where maximum camber occurs.
c.	Aerodynamic Section
TITLE3 A title card for the aerodynamic section of the program.	
CP	Specific heat at constant pressure. An input value of zero will be reset to 0.24. Units: H/F/D.
GASR	Gas constant. An input value of zero will be reset to 53.32. Units: L/SCLFAC/D.
G	Acceleration due to gravity. An input value of zero will be reset to 32.174. Units: L/SCLFAC/T/T.
EJ	Joules equivalent. An input value of zero will be reset to 778.16. Units: LF/SCLFAC/H.
NSTNS	Number of computing stations. Must satisfy $3 \leq \text{NSTNS} \leq 30$.
NSTRMS	Number of streamlines. Must satisfy $3 \leq \text{NSTRMS} \leq 21$. An input value of zero will be reset to 11.
NMAX	Maximum number of passes through the iterative streamline determination procedure. An input value of zero will be reset to 40.
NFORCE	The first NFORCE passes are performed with arbitrary numbers inserted should any calculation produce impossible values. Thereafter, execution will cease, the calculation having "failed". An input value of zero will be reset to 10.
NBL	If NBL = 0, the annulus wall boundary layer blockage allowance will be held at the values prescribed by WBLOCK. If NBL = 1, blockage due to annulus wall boundary layers will be recalculated except at station 1. VISK and SHAPE are used in the calculation.

NCASE	Set NCASE = 1.
NSPLIT	If NSPLIT = 0, the flow distribution between the streamlines will be determined by the program so that roughly uniform increments of computing station will occur between the streamlines at station 1. If NSPLIT = 1, the flow distribution between the streamlines is read in (see DELF).
NSET1	The blade loss coefficient re-evaluation option (specified by NEVAL) requires loss parameter/diffusion factor data. NSET1 sets of data are input, the set numbers being allocated according to the order in which they are input. Up to 4 sets may be input (see NDIFF).
NSET2	When NLOSS = 4, the loss coefficients at the station are determined as a fraction of the value at the trailing edge. Then, NSET2 sets of curves are input to define this fraction as a function of radius and meridional chord. Up to 2 sets may be input (see NM).
NREAD	If NREAD = 0, the initial streamline pattern estimate is generated by the program. If NREAD = 1, the initial streamline pattern estimate and also the DELF values are read in. (See DELF, R, X, XL.)
NPUNCH	Set NPUNCH = 0
NPLOT	Set NPLOT = 0
NPAGE	The maximum number of lines printed per page. An input value of zero will be reset to 60.
NTRANS	IF NTRANS = 0, no action is taken. If NTRANS = 1, relative total pressure loss coefficients will be modified to account for radial transfer of wakes. See Section V.11, Ref. .

NMIX If NMIX = 0, no action is taken.
 If NMIX = 1, entropy, angular momentum,
 and total enthalpy distributions will
 be modified to account for turbulent
 mixing. See Section V.12, Ref. .

NMANY The number of computing stations for
 which blade descriptive data is being
 generated by the analytic meanline
 section.

NSTPLT If NSTPLT = 0, no action is taken.
 If NSTPLT = 1, a line-printer plot of the
 changes made to the midstreamline ' ℓ '
 coordinate is made for each computing
 station. If more than 59 passes through
 the iterative procedure have been made, then
 the plots will show the changes for the
 last 59 passes. The graph should decay approxi-
 mately exponentially towards zero, indicating
 that the streamline locations are stabilizing.
 Decaying oscillations are equally acceptable,
 but, growing oscillations show the need for
 heavier damping in the streamline relocation
 calculations, that is, a decrease in RCONST.

NEQN This item controls the selection of the
 form of momentum equation that will be used
 to compute the meridional velocity distri-
 butions at each computing station. There are

two basic forms, and for each case, one may select not to compute the terms relating to blade forces. (See also Section V. 1, Ref. .

If NEQN = 0, the momentum equation involves the differential form of the continuity equations and hence $(1-M_m^2)$ terms in the denominator. Streamwise gradients of entropy and angular momentum (blade forces) are computed within blades and at the blade edges (provided data that describe the blades are given). Elsewhere, streamwise entropy gradients only are included in a simpler form of the momentum equation, except that at the first and last computing station, all streamwise gradients are taken to be zero. This is generally the preferred option when computing stations are located within the blade rows.

If NEQN = 1, the momentum equation form is similar to that used when NEQN = 0, but angular momentum gradients (blade force terms) are nowhere computed. This generally is the preferred option when computing stations are located at the blade edges only.

If NEQN = 2, the momentum equation includes an explicit dV_m/dm term instead of the $(1-M_m^2)$

denominator terms. All streamwise gradients (including blade force terms) are computed as for the case NEQN = 0. When computing stations are located within the blade rows, the results will generally be similar to those obtained with NEQN = 0, and solutions may be found that cannot be computed with NEQN = 0 due to high meridional Mach numbers.

If NEQN = 3, the momentum equation is similar to that used when NEQN = 1, but (as for the case NEQN = 1) no angular momentum gradients are computed. This may be used when computing stations are located only at the blade edges and high meridional Mach numbers preclude the use of NEQN = 1.

NLE
NTE
NSIGN

See the Analytic Section.

NWHICH

The numbers of each of the computing stations for which blade descriptive data is being generated by the analytic meanline section.

SCLFAC

Linear dimension scale factor , see page . An input value of zero will be reset to 12.0.

TOLNCE

Basic tolerance in iterative calculation scheme. An input value of zero will be reset to 0.001. (See discussion of tolerance scheme in Section VI, Ref. .)

VISK	Kinematic viscosity of gas (for annulus wall boundary layer calculations). An input value of zero will be reset to 0.00018. Units: LL/SCLFAC/SCLFAC/T.
SHAPE	Shape factor for annulus wall boundary layer calculations. An input value of zero will be reset to 0.7.
XSCALE PSCALE RLOW PLOW	Set each equal to 0.0.
XMMAX	The square of the Mach number that appears in the equation for the streamline relocation relaxation factor is limited to be not greater than XMMAX. Thus, at computing stations where the appropriate Mach number is high enough for the limit to be imposed, a decrease in XMMAX corresponds to an increase in damping. If a value of zero is input, it is reset to 0.6.
RCONST	The constant in the equation for the streamline relocation relaxation factor. The value of 8.0 that the analysis yields is often too high for stability. If zero is input, it is reset to 6.0.
CONTR	The constant in the blade wake radial transfer calculations.
CONMX	The eddy viscosity for the turbulent mixing calculations. Units: $L^2/SCLFAC^2/T$.

FLOW	Compressor flow rate. Units: F/T.
SPDFAC	The speed of rotation of each computing station is SPDFAC times SPEED (I). The units for the product are revolutions/(60xT).
NSPEC	The number of points used to define a computing station. Must satisfy $2 \leq NSPEC \leq 21$, and also the sum of NSPEC for all stations ≤ 150. If 2 points are used, the station is a straight line. Otherwise, a spline-curve is fitted through the given points.
XSTN, RSTN	The axial and radial coordinates, respectively, of a point defining a computing station. The first point must be on the hub and the last point must be on the casing. Units: L.
NDATA	Number of points defining conditions or blade geometry at a computing station. Must satisfy $0 \leq NDATA \leq 21$, and also the sum of NDATA for all stations ≤ 100.
NTERP	If NTERP = 0, and NDATA ≥ 3, interpolation of the data at the station is by spline-fit. If NTERP = 1 (or NDATA ≤ 2), interpolation is linear point-to-point.
NDIMEN	If NDIMEN = 0, the data are input as a function of radius. If NDIMEN = 1, the data are input as a function of radius normalized with respect to tip radius. If NDIMEN = 2, the data are input as a function of distance along the computing station from the hub. If NDIMEN = 3, the data are input as a function of distance along the computing station normalized with respect to the total computing station length.
NMACH	If NMACH = 0, the subsonic solution to the continuity equation is sought. If NMACH = 1, the supersonic solution to the continuity equation is sought. This should only be used at stations where the relative flow angle is specified, that is, NWORK = 5, 6, or 7.
DATAC	The coordinate on the computing station, defined according to NDIMEN, where the following data items apply. Must increase monotonically. For dimensional cases, units are L.

DATA1

At Station 1 and if NWORK = 1, DATA1 is total pressure. Units: F/L/L.
If NWORK = 0 and the station is at a blade leading edge, by setting NDATA ≠ 0, the blade leading edge may be described. Then DATA1 is the blade angle measured in the cylindrical plane. Generally negative for a rotor, positive for a stator. (Define the blade lean angle (DATA3) also). Units: A.
If NWORK = 2, DATA1 is total enthalpy. Units: H/F.

If NWORK = 3, DATA1 is angular momentum (radius times absolute whirl velocity). Units: LL/SCLFAC/T.

If NWORK = 4, DATA1 is absolute whirl velocity. Units: L/SCLFAC/T.

If NWORK = 5, DATA1 is blade angle measured in the stream surface plane. Generally negative for a rotor, positive for a stator. If zero deviation is input, it becomes the relative flow angle. Units: A.

If NWORK = 6, DATA1 is the blade angle measured in the cylindrical plane. Generally negative for a rotor, positive for a stator. If zero deviation is input, it becomes, after correction for stream surface orientation and station lean angle, the relative flow angle. Units: A.

If NWORK = 7, DATA1 is the reference relative outlet flow angle measured in the stream surface plane. Generally negative for a rotor, positive for a stator. Units: A.

DATA2

At Station 1, DATA2 is total temperature. Units: D.

If NLOSS = 1, DATA2 is the relative total pressure loss coefficient. The relative total pressure loss is measured from the station that is NL1 stations removed from the current station, NL1 being negative to indicate an upstream station. The relative dynamic head is determined NL2 stations removed from the current station, positive for a downstream station, negative for an upstream station.

If NLOSS = 2, DATA2 is the isentropic efficiency of compression relative to conditions NL1 stations removed, NL1 being negative to indicate an upstream station.

If NLOSS = 3, DATA2 is the entropy rise relative to the value NL1 stations removed, NL1 being negative to indicate an upstream station. Units: H/F/D.

If NLOSS = 4, DATA2 is not used, but a relative total pressure loss coefficient is determined from the trailing edge value and curve set number NCURVE of the NSET2 families of curves. NL1 and NL2 apply as for NLOSS = 1.

If NWORK = 7, DATA2 is the reference (minimum) relative total pressure loss coefficient. NL1 and NL2 apply as for NLOSS = 1.

DATA3

The blade lean angle measured from the projection of a radial line in the plane of the computing station, positive when the innermost portion of the blade precedes the outermost in the direction of rotor rotation. Units: A.

DATA4

The fraction of the periphery that is blocked by the presence of the blades.

DATA5

Cascade solidity. When a number of stations are used to describe the flow through a blade, values are only required at the trailing edge. (They are used in the loss coefficient re-estimation procedure, and to evaluate diffusion factors for the output.)

DATA6

If NWORK = 5 or 6, DATA6 is the deviation angle measured in the streamsurface plane. Generally negative for a rotor, positive for a stator. Units: A.

If NWORK = 7, DATA6 is reference relative inlet angle, to which the minimum loss coefficient (DATA2) and the reference relative outlet angle (DATA7) correspond. Measured in the streamsurface plane and generally negative for a rotor, positive for a stator. Units: A.

DATA7

If NWORK = 7, DATA7 is the rate of change of relative outlet angle with relative inlet angle.

DATA8

If NWORK = 7, DATA8 is the relative inlet angle larger than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.

DATA9	If NWORK = 7, DATA9 is the relative inlet angle smaller than the reference value at which the loss coefficient attains twice its reference value. Measured in the streamsurface plane. Units: A.
NWORK	<p>If NWORK = 0, constant entropy, angular momentum, and total enthalpy exist along streamlines from the previous station. (If NMIX = 1, the distributions will be modified.)</p> <p>If NWORK = 1, the total pressure distribution at the computing station is specified. Use for rotors only.</p> <p>If NWORK = 2, the total enthalpy distribution at the computing station is specified. Use for rotors only.</p> <p>If NWORK = 3, the absolute angular momentum distribution at the computing station is specified.</p> <p>If NWORK = 4, the absolute whirl velocity distribution at the computing station is specified.</p> <p>If NWORK = 5, the relative flow angle distribution at the station is specified by giving blade angles and deviation angles, both measured in the streamsurface plane.</p> <p>If NWORK = 6, the relative flow angle distribution at the station is specified by giving the blade angles measured in the cylindrical plane, and the deviation angles measured in the streamsurface plane.</p> <p>If NWORK = 7, the relative flow angle and relative total pressure loss coefficient distributions are specified by means of an off-design analysis procedure. "Reference", "stalling", and "choking" relative inlet angles are specified. The minimum loss coefficient varies parabolically with the relative inlet angle so that it is twice the minimum value at the "stalling" or "choking" values. A maximum value of 0.5 is imposed. "Reference" relative outlet angles and the rate of change of outlet angle with inlet angle are specified, and the relative outlet angle varies linearly from the reference value with the relative inlet angle. NLOSS should be set to zero.</p>
NLOSS	<p>If NLOSS = 1, the relative total pressure loss coefficient distribution is specified.</p> <p>If NLOSS = 2, the isentropic efficiency (for compression) distribution is specified.</p> <p>If NLOSS = 3, the entropy rise distribution is specified.</p>

If NLOSS = 4, the total pressure loss coefficient distribution is specified by use of curve-set NCURVE of the NSET2 families of curves giving the fraction of final (trailing edge) loss coefficient.

- NL1 The station from which the loss(in whatever form NLOSS specifies) is measured, is NL1 stations removed from the station being evaluated. NL1 is negative to indicate an upstream station.
- NL2 When a relative total pressure loss coefficient is used to specify losses, the relative dynamic head is taken NL2 stations removed from the station being evaluated. NL2 may be positive, zero, or negative; a positive value indicates a downstream station, a negative value indicates an upstream station.
- NEVAL If NEVAL = 0, no action is taken.
If NEVAL > 0, curve-set number NEVAL of the NSET1 families of curve giving diffusion loss parameter as a function of diffusion factor will be used to re-estimate the relative total pressure loss coefficient. NLOSS must be 1, and NL1 and NL2 must specify the leading edge of the blade. See also NDEL.
- If NEVAL 0, curve-set number NEVAL is used as NEVAL 0, except that the re-estimation is only made after the overall computation is completed (with the input losses). The resulting loss coefficients are displayed but not incorporated into the overall calculation. See also NDEL.
- NCURVE When NLOSS = 4, curve-set NCURVE of the NSET2 families of curves, specifying the fraction of trailing-edge loss coefficient as a function of meridional chord is used.

NLITER When NEVAL > 0, up to NLITER re-estimations of the loss coefficient will be made at a given station during any one pass through the overall iterative procedure. Less than NLITER re-estimations will be made if the velocity profile is unchanged by re-estimating the loss coefficients. (See discussion of tolerance scheme in Section VI, Ref .)

NDEL When NEVAL = 0, set NDEL to 0. When NEVAL ≠ 0, and NDEL > 0, a component of the re-estimated loss coefficient is a shock loss. The relative inlet Mach number is expanded (or compressed) through a Prandtl-Meyer expansion on the suction surface, and NDEL is the number of points at which the Prandtl-Meyer angle is given. If NDEL = 0, the shock loss is set at zero. Must satisfy $0 \leq NDEL \leq 21$, and also the sum of NDEL for all stations ≤ 100 .

NOUT1 Set NOUT1 = 0

NOUT2 Set NOUT2 = 0

NOUT3 This data item controls the generation of NASTRAN - compatible temperature and pressure difference output for use in subsequent blade stress analyses. For details of the triangular mesh that is used, see the Output Description in Section .

NOUT3 = XY, where

If X = 1, the station is at a blade leading edge.

If X = 2, the station is at a blade trailing edge.

If Y = 0, then both temperature and pressure data will be generated.

If Y = 1, then only pressure data will be generated.

If Y = 2, then only temperature data will be generated.

If NOUT3 = 0, the station may be between blade rows, or within a blade row for which output is required, depending upon the use of NOUT3 ≠ 0 elsewhere. See also description of NBLADE below.

NBLADE

This item is used in determining the pressure difference across the blade. The number of blades is | NBLADE | . If NBLADE is positive, "three-point averaging" is used to determine the pressure difference across each blade element. If NBLADE is negative, "four point averaging" is used.

(See the Output Description in Section .)

If NBLADE is input as zero, a value of +10 is used. At a leading edge, the value for the following station is used: elsewhere the value at a station applies to the interval

upstream of the station. Thus by varying the sign of NBLADE, the averaging method used for the pressure forces may be varied for different axial segments of a blade row.

SPEED This card is omitted if NDATA = 0. The speed of rotation of the blade. At a blade leading edge, it should be set to zero. The product SPDFAC times SPEED has units of revolutions/(T x 60).

DELC The coordinate at which Prandtl-Meyer expansion angles are given. It defines the angle as a function of the dimensions of the leading edge station, in the manner specified by NDIMEN for the current, that is trailing edge station. Must increase monotonically. For dimensional cases, units are L.

DELTA The Prandtl-Meyer expansion angles. A positive value implies expansion. If blade angles are given at the leading edge, the incidence angles are added to the value specified by DELTA. Units: A. (Blade angles are measured in the cylindrical plane.)

WBLOCK A blockage factor that is incorporated into the continuity equation to account for annulus wall boundary layers. It is expressed as the fraction of total area at the computing station that is blocked. If NBL = 1, values (except at Station 1) are revised during computation, involving data items VISK and SHAPE.

BBLOCK, BDIST	A blockage factor is incorporated into the continuity equation that may be used to account for blade wakes or other effects. It varies linearly with distance along the computing station. BBLOCK is the value at mid-station (expressed as the fraction of the periphery blocked), and BDIST is the ratio of the value on the hub to the mid-value.
NDIFF	When NSET1> 0, there are NDIFF points defining loss diffusion parameter as a function of diffusion factor. Must satisfy 1 ≤ NDIFF ≤ 15.
DIFF	The diffusion factor at which loss parameters are specified. Must increase monotonically.
FDHUB	Diffusion loss parameter at 10 per cent of the radial blade height.
FDMID	Diffusion loss parameter at 50 per cent of the radial blade height.
FDTIP	Diffusion loss parameter at 90 per cent of the radial blade height.
NM	When NSET2> 0, there are NM points defining the fraction of trailing edge loss coefficient as a function of meridional chord. Must satisfy 1 ≤ NM ≤ 11.
NRAD	The number of radial locations where NM loss fraction/chord points are given. Must satisfy 1 ≤ NRAD ≤ 5.
TERAD	The fraction of radial blade height at the trailing edge where the following loss fraction/chord curve applies. If NRAD = 1, it has no significance.
DM	The location on the meridional chord where the loss fraction is given. Expressed as a fraction of meridional chord from the leading edge. Must increase monotonically.
WFRAC	Fraction of trailing edge loss coefficient that occurs at location DM.

DELF The fraction of the total flow that is to occur between the hub and each streamline. The hub and casing are included, so that the first value must be 0.0, and the last (NSTRM) value must be 1.0.

R Estimated streamline radius. (These data are input from hub to tip for the first station, from hub to tip for the second station, and so on.) Units: L.

X Estimated axial coordinate at intersection of streamline with computing station. Units: L.

XL Estimated distance along computing station from hub to intersection of streamline with computing station. Units: L.

II, JJ Station and streamline number. These are merely read in and printed out to give a check on the order of the cards.

1.15.3.2 AERODYNAMIC OUTPUT DATA

1. ANALYTIC MEANLINE SECTION

Printed output may be considered to consist of four sections; a printout of the input data, details of the blade sections on each streamsurface, a listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below. In the explanation which follows, parenthetical statements are understood to refer to the particular case of the double-circular-arc blade (ISECN = 2).

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the parameters defining the blade section. These are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the section specified, except that the meridional projection of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord; stagger angle; camber angle; section area; location of the centroid of the section; second moments of area of the section about the centroid; orientation of the principal axes; and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. NPOINT values are given.

A lineprinter plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page, so that the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give a blade section as defined by IFCORD and CORD. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord; radius and location of center of leading (and trailing) edge(s); section area, the second moments of area of the section about the centroid and the principal second moments of area of the section about the centroid. The coordinates of NPOINT points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at (roughly) six degree intervals around the leading (and trailing) edges. Finally, the coordinates of the blade surfaces and points around the leading (and trailing) edge(s) is (are) shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, blade section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station. The blade section angle is measured in the cylindrical plane, and the blade lean angle is measured in the constant-axial-coordinate plane.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER, and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area; the location of the centroid of the section; the second moments of area of the section about the centroid; the principal second moments of area of the section about the centroid; the orientation of the principal axes; and the section torsional constant. Then the coordinates of NPOINT points on the blade section surfaces are listed, followed by 31 points around the leading (and trailing) edge(s).

If NAERO = 1, the additional input and output required for, and generated by, the interface are also printed. (Apart from the input data printout, this is the only printed output when IPRINT = 3.)

If the NASTRAN parameter PGEOM \neq -1 then cards are punched that may be used as input for the NASTRAN stress analysis program. For the purpose of stress analysis, the blade is divided into a number of triangular elements, each defined by three grid points. The intersections between computing stations and streamsurfaces are used as the grid points and the grid points and element numbering scheme adopted is illustrated in Figure 1.

The NASTRAN input data format includes cards identified by the codes GRID, CTRIA2 and PTRIA2. The data are fully described in Reference 7, but briefly, the GRID cards each define a grid point number and give the coordinates at the grid point, the CTRIA2 cards each define an element in terms of the three appropriate grid points (by number, and in a significant order), the PTRIA2 cards each give an average blade thickness for an element.

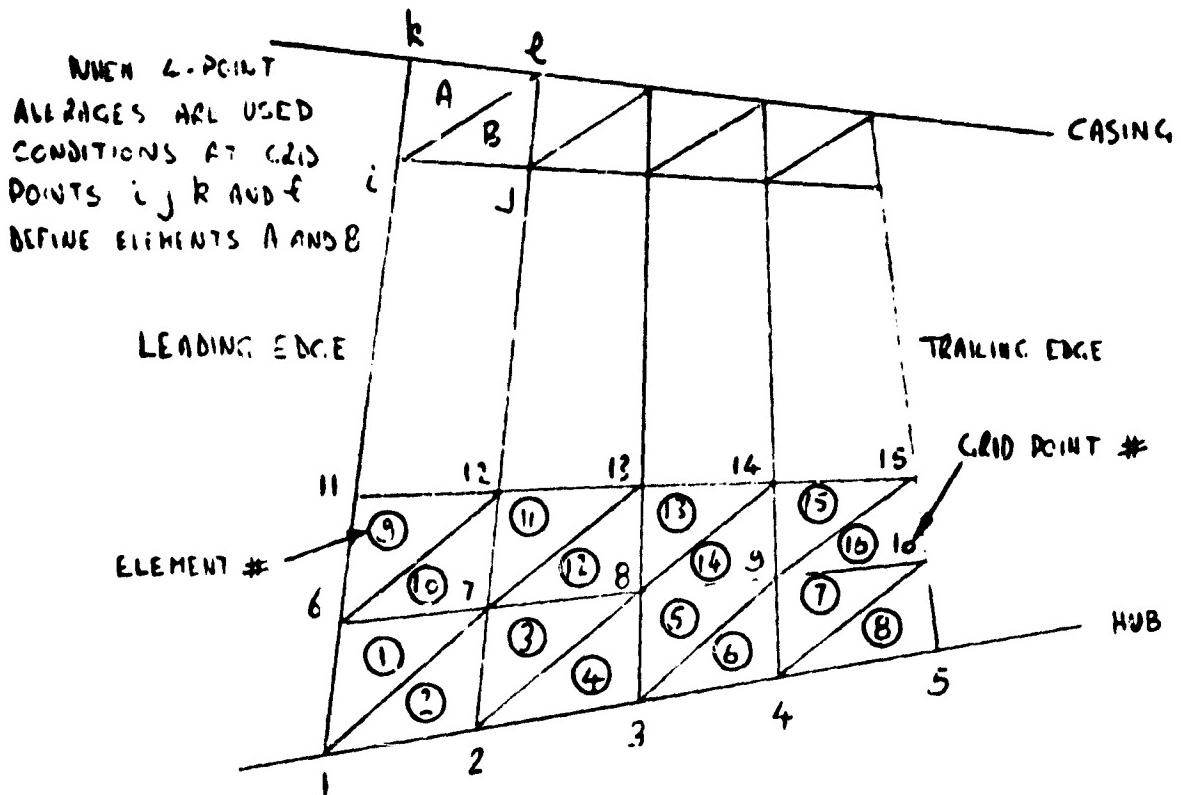


Figure 1. NASTRAN Grid Point and Element Numbering Scheme.

2. AERODYNAMIC SECTION

a. Regular Printed Output

The input data are first printed out in its entirety, and the results for each running point follow. The output is generally self-explanatory and definitions are given here for some derived quantities. Tabular output is generally not started on a page unless it can be completed on the same page, according to the maximum number of lines permitted by the input variable NPAGE.

The results of each running point are given under a heading giving the running point number. Any diagnostics generated during the calculation will appear first under the heading. (Diagnostics are described in the following section.) Then, a station-by-station print out follows for

each station through to the last station, or to the station where the calculation failed, if this occurred. One or more diagnostics will indicate the reason for the failure, in this event. Included in the meshpoint coordinate data is the distance along the computing station from the hub to the interception of the streamline with the station (L), and the station lean angle ($GAMA$). Where the radius of curvature of a streamline is shown as zero, the streamline has no curvature. The whirl angle is defined by

$$\tan \alpha = \frac{V_\theta}{V_m} \quad (1)$$

For stations within a blade, or at a blade trailing edge, a relative total pressure loss coefficient is shown. The loss of relative total pressure is computed from the station defined by the input variable $NL1$. If a loss coefficient was used in the input for the station ($NLOSS = 1$ or 4 , or $NWORK = 7$), the input variable $NL2$ defines the station where the normalizing relative dynamic head is taken; otherwise, it is taken at the station defined by $NL1$. If the cascade solidity is given as anything but zero, it is used in the determination of diffusion factors. The following definition is used:

$$D = 1 - \frac{V_{1r}}{V_{ir}} + \frac{V_{\theta 1r} V_{\theta 2r}}{2\sigma V_{ir}} \quad (2)$$

Inlet conditions (subscript 1) are taken from the station defined by the input variable $NL1$.

The last term in Equation 2 is multiplied by -1 if the blade speed is greater than zero, or the blade speed is zero and the preceding rotating blade row has negative rotation. This is necessary because relative whirl angles are (generally) negative for rotor blades and for stator blades that follow a rotor having "negative" wheel speed. Incidence and deviation angles are treated in the same way, so that positive and negative values have their conventional significance for all blades.

If annulus wall boundary layer computations were made ($NBL = 1$), details are shown for each station. Then, an overall result is given, including a statement of the number of passes that have been performed and whether the calculation is converged, un converged, or failed. When the calculation is un converged, the number of mesh points where the meridional velocity component has not remained constant to within the specified

tolerance (TOLNCE) on the last two passes is shown as IVFAIL. Similarly, the number of streamtubes, defined by the hub and each streamline in turn, where the fraction of the flow is not within the same tolerance of the target value is shown as IFFAIL. If these numbers are small, say less than 10% of the maximum possible values, the results may generally be used. Otherwise, the computation should be rerun, either for a greater number of passes, or with modified relaxation factor constants. The default option relaxation constants will generally be satisfactory but may need modification for some cases. If insufficient damping is specified by the constants, the streamlines generated will tend to oscillate and this may be detected by observing a relatively small radius of curvature for the mid-passage streamline that also changes sign from one station to the next. This may be corrected by rerunning the problem (from scratch) with a lower value input for RCONST, say, of 4.0 instead of 6.0. When the damping is excessive, the velocities will tend to remain constant while the streamlines will not adjust rapidly to the correct locations. This will be indicated by a small IVFAIL and a relatively large IFFAIL. For optimum program performance, RCONST should be increased, and the streamline pattern generated thus far could be used as a starting point. The second constant XMMAX (the maximum value of the square of Mach number used in the relaxation factor) is incorporated so that in high subsonic or supersonic cases the damping does not decrease unacceptably. The default value of 0.6 may be too low for rapid program convergence in some such cases.

If the generation of blade pressure load data for the NASTRAN program is specified (by the input variable NOUT3), a self-explanatory printout is also made. The blade element numbering scheme is the same as that incorporated into both blading sections of the program, and illustrated in Figure 1.

If the loss coefficient re-estimation routine has been used for any bladerow(s) (NEVAL ≠ 0), a printout summarizing the computations made will follow. A heading indicating whether the re-estimation was incorporated into the overall iterative procedure or whether it was merely made "after the event" is first printed. Then follows a self-explanatory tabulation of various quantities involved in the redetermination of the loss coefficient on each streamline.

b. Diagnostic Printed Output

The various diagnostic messages that may be produced by the aerodynamic section of the program are all shown. Where a computed value will occur, "x" is shown here.

JOB STOPPED - TOO MUCH INPUT DATA

The above message will occur if the sum of NSPEC or NDATA or NDEL for all stations is above the permitted limit. Execution ceases.

STATIC ENTHALPY BELOW LIMIT AT xxx.xxxxxExx

The output routine (subroutine UD0311) calculates static enthalpy at each meshpoint when computing the various output parameters and this message will occur if a value below the limit (HMIN) occurs. The limiting value will be used, and the results printed become correspondingly arbitrary. HMIN is set in the Program UD03AR and should be maintained at some positive value well below any value that will be validly encountered in calculation.

PASSxxx STATIONxxx STREAMLINExxx PRANDTL-MEYER
FUNCTION NOT CONVERGED - USE INLET MACH NO

The loss coefficient re-estimation procedure involves iteratively solving for the Mach number in the Prandtl-Meyer function. If the calculation does not converge in 20 attempts, the above message is printed, and as indicated, the Mach number following the expansion (or compression) is assumed to equal the inlet value. (The routine only prints output following the completion of all computations and printing of the station-by-station output data.)

PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
MERIDIONAL VELOCITY UNCONVERGED VM = xx.xxxxxxExx
VM(OLD) = xx.xxxxxxExx

For "analysis" cases, that is at stations where relative flow angle is specified, the calculation of meridional velocity proceeds iteratively at each meshpoint from the mid-streamline to the case and then to the hub. The variable LPMAX (set to 10 in Subroutines UD0308 and UD0326) limits the maximum number of iterations that may be made at a streamline without the velocity being converged before the calculation proceeds to the next streamline. The above message will occur if all iterations are used without achieving convergence, and the pass number is greater than NFORCE. Convergence is here defined as occurring when the velocity repeats to within TOLNCE/5.0, applied nondimensionally. No other program action occurs.

PASSxxx STATIONxxx MOMENTUM AND/OR CONTINUITY
UNCONVERGED W/W SPEC = xx.xxxxx VM/VM (OLD) HUB =
xx.xxxxxMID=xx.xxxxx TIP = xx.xxxxx

If, following completion of all ITMAX iterations permitted for the flow rate or meridional velocity, the simultaneous solution of the momentum and continuity equations profile is un converged, and the pass number is greater than NFORCE, the above message occurs. Here converged means that the flow rate equals the specified value, and the meridional velocity repeats, to within TOLNCE/5.0, applied nondimensionally. If loss coefficient re-estimation is specified (NEVAL > 0), an additional iteration is involved, and the tolerance is halved. No further program action occurs.

PASSxxx STATIONxxx VM PROFILE NOT CONVERGED WITH
LOSS RECALC VM NEW/VM PREV HUB = xx.xxxxxx MID =
xx.xxxxxx CASE = xx.xxxxxx

When loss re-estimation is specified (NEVAL > 0), up to NLITER solutions to the momentum and continuity equations are completed, each with a revised loss coefficient variation. If, when the pass number is greater than NFORCE, the velocity profile is not converged after the NLITER cycles of calculation have been performed, the above message is issued. For convergence, the meridional velocities must repeat to within TOLNCE/5.0, applied nondimensionally. No further program action occurs.

A further check on the convergence of this procedure is to compare the loss coefficients used on the final pass of calculation, and thus shown in the station-by-station results, with those shown in the output from the loss coefficient re-estimation routine, which are computed from the final velocities, etc.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBE_{Exxx} STATIC ENTHALPY BELOW LIMIT IN MOMENTUM EQUATION AT xxx. xxxxExxx

The static enthalpy is calculated (to find the static temperature) during computation of the "design" case momentum equation, that is, when whirl velocity is specified. If a value lower than HMIN (see discussion of second diagnostic message) is produced, the limiting value is inserted. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBE_{Exxx} LOOP_{xxx} STATIC H IN MOMENTUM EQUN. BELOW LIMIT AT xxx. xxxxExxx

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur on the final iteration and loop.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBE_{Exxx} MERIDIONAL MACH NUMBER ABOVE LIMIT AT xxx. xxxxExxx

When Subroutine UD0308 is selected (NEQN = 0 or 1), the meridional Mach number is calculated during computation of the design momentum equation, and a maximum value of 0.99 is permitted. If a higher value is calculated, the limiting value is inserted. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBE_{Exxx} LOOP_{xxx} MERIDIONAL MACH NUMBER ABOVE LIMIT AT xxx. xxxxExxx

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur at the final iteration and loop.

PASSxxx STATIONxxx ITERATIONxxx STREAMTUBE_{Exxx} MOMENTUM EQUATION EXPONENT ABOVE LIMIT AT xxx. xxxxExxx

An exponentiation is performed during the computation of the design case momentum equation, and the maximum value of the exponent is limited to 88.0. If this substitution is required when IPASS > NFORCE, the above message is printed. If it occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

**PASSxxx STATIONxxx ITERATIONSxxx STREAMLINExxx
(MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT
xxx. xxxxExxx.**

If a meridional velocity, squared, of less than 1.0 is calculated during computation of the design-case momentum equation, this limit is imposed. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed out through to this station.

**PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx LOOPxxx
(MERIDIONAL VELOCITY) SQUARED BELOW LIMIT AT
xxx. xxxxExxx.**

This corresponds to the previous message, but for the "analysis" case. For failure, it must occur on the last iteration and loop.

**PASSxxx STATIONxxx ITERATIONxxx STREAMTUBExxx
STATIC ENTHALPY BELOW LIMIT IN CONTINUITY EQUATION
AT xxx. xxxxExxx.**

The static enthalpy is calculated during computation of the continuity equation. If a value lower than HMIN (see discussion of second diagnostic message) is produced, the limiting value is imposed. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed out through to this station.

**PASSxxx STATIONxx ITERATIONxxx STREAMLINExxx
MERIDIONAL VELOCITY BELOW LIMIT IN CONTINUITY AT
xxx. xxxxExxx.**

If a meridional velocity of less than 1.0 is calculated when the velocity profile is incremented by the amount estimated to be required to satisfy continuity, this limit is imposed. If this occurs when IPASS > NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station.

**PASSxxx STATIONxxx ITERATIONxxx OTHER CONTINUITY
EQUATION BRANCH REQUIRED**

If when IPASS>NFORCE, a velocity profile is produced that corresponds to a subsonic solution to the continuity equation when a supersonic solution is required, or vice versa, the above message is printed. If this occurs on the final iteration, failure is deemed to have occurred, calculation ceases, and results are printed out through to this station.

**PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
MERIDIONAL VELOCITY GREATER THAN TWICE MID VALUE**

During integration of the "design" momentum equations, no meridional velocity is permitted to be greater than twice the value on the mid-streamline. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station. In the event that this limit interferes with a valid velocity profile, the constants that appear on cards \$08\$.272, \$08\$.279, \$26\$.229, and \$26\$.236 may be modified accordingly. Note that as the calculation is at this point working with the square of the meridional velocity, the constant for a limit of 2.0 times the mid-streamline value, for instance, appears as 4.0.

**PASSxxx STATIONxxx ITERATIONxxx STREAMLINExxx
LOOPxxx MERIDIONAL VELOCITY ABOVE LIMIT xxxxxExx
LIMIT = xxxxxExx.**

During integration of the "analysis" momentum equations, no meridional velocity is permitted to be greater than three times the value on the mid-streamline. If this occurs when IPASS>NFORCE, the above message is printed. If this occurs on the final loop of the final iteration, the calculation is deemed to have failed, calculation ceases, and results are printed through to this station. In the event that the limit interferes with a valid velocity profile, the constants that appear on cards \$08\$.398, \$08\$.409, \$26\$.323, \$26\$.334, and \$26\$.329 may be modified accordingly. In each case except that of the last card noted, the program is working with meridional velocity squared, so that a limit of, for instance, 3.0 times the mid-streamline value appears as 9.0.

**PASSxxx STATIONxxx STREAMLINExxx LIMITING MERIDIONAL
VELOCITY SQUARED = xxxxxExx.**

In the Subroutine UD0308 (NEQN= 0 or 1), a maximum permissible meridional velocity (equal to the speed of sound) is established for each streamline at the beginning of each pass. The calculation yields the square of the velocity, and if a value of less than 1.0 is obtained, a value of 6250000.0 is superimposed (which corresponds to a meridional velocity of 2500.0). If this occurs when IPASS>NFORCE, the above message is printed, and the calculation is deemed to have failed. Calculation ceases after the station computations are made, and results are printed through to this station.

PASSxxxx STATIONxxxx ITERATIONxxxx STREAMLINExxxx
MERIDIONAL VELOCITY ABOVE SOUND SPEED VM =
xxxx. xx A = xxxx. xx.

In Subroutine UD0308 (NEQN = 0 or 1), no meridional velocity is permitted to be larger than the speed of sound. The above message will occur if this limit is violated during integration of the "design" momentum when IPASS > NFORCE. If the limit is violated at any point when IPASS > NFORCE and on the last permitted iteration (last permitted loop also in the case of the "analysis" momentum equation), the calculation is deemed to have failed. Calculation ceases, and the results are printed through to this station.

MIXING CALCULATION FAILURE NO. n

The above message occurs when flow mixing calculations are specified, and the computation fails. The overall calculation is halted, and results are printed through to the station that is the upstream boundary for the mixing interval in which the failure occurred. The integer n takes on different values to indicate the specific problems as follows.

- n = 1** In solving for the static pressure distribution at the upstream boundary of each mixing step, the average static enthalpy is determined in each streamtube (defined by an adjacent pair of streamlines). This failure indicates that a value less than HMIN was determined.
- n = 2** Calculation of the static pressure distribution at the upstream boundary of the mixing step is iterative. This failure indicates that the procedure was not converged after 10 iterations.
- n = 3** The static enthalpy on each streamline at the mixing step upstream boundary is determined from the static pressure and entropy there. This failure indicates that a value less than HMIN was determined.
- n = 4** The axial velocity distribution at the mixing step upstream boundary is determined from the total enthalpy, static enthalpy, and tangential velocity distributions. This failure indicates that a value less than VMIN was determined.
- n = 5** In solving for the static pressure distribution at the downstream boundary of each mixing step, the average static enthalpy is determined in each streamtube (defined by an adjacent pair of streamlines). This failure indicates that a value less than HMIN was determined.

$n = 6$ Calculation of the static pressure distribution at the downstream boundary of the mixing step is iterative. This failure indicates that the procedure was not converged after 10 iterations.

$n = 7$ The static enthalpy distribution at the mixing step downstream boundary is found from the total enthalpy, axial velocity, and tangential velocity distributions. This failure indicates that a value less than HMIN was determined.

$n = 8$ In order to satisfy continuity, the static pressure level at the mixing step downstream boundary is iteratively determined. This failure indicates that after 15 attempts, the procedure was un converged.

c. Aerodynamic Load and Temperature Output

Four output options may result in cards being produced by the aerodynamic section of the program. Use of the input item NOUT3 gives "PLOAD2 and Temperature - Cards" punched in a format compatible with the NASTRAN stress program. For the purposes of stress analysis, the blade is taken to be composed of a number of triangular elements. Two such elements are formed by the quadrilateral defined by two adjacent streamlines and two adjacent computing stations. The way that each quadrilateral is divided into two triangles, and the element numbering scheme that is used, are illustrated in Figure 1. The pressure difference for each element is given by an average of either three or four values at surrounding meshpoints. The pressure difference at each meshpoint is computed from the equation

$$\Delta p = \frac{2\pi r f}{N} \left\{ \sin \beta \cos \beta g J + \frac{dS}{dm} + \frac{V_m}{r} \frac{d(r V_\theta)}{dm} \right\} \quad (3)$$

and as follows. At the blade leading edge a forward difference is used to determine the meridional gradients. At the blade trailing edge the pressure difference is taken to be zero. At stations with the bladerow (following a leading edge), mean central differences are used to determine the meridional gradients. When the input item NBLADE is positive (or zero) for a particular

blade axial segment, then three-point averaging is used. For instance, for element number 1 in Figure 1, pressure differences at grid points 1, 6, and 7 would be used. If NBLADE is negative, four-point averaging is used. For instance for element number 1, pressure differences at grid points 1, 2, 6 and 7 would be used. The same average would also apply to element number 2. Relative total temperatures are output at the grid points on the blade. A TEMPD value is also output using the average temperature at the blade root for the grid points on the rest of the structure.

1.15.4

~~Sample Problem~~

To be written

USER'S MANUAL UPDATES

1.15.4 Sample Problem

The Static Aerothermoelastic Design/Analysis procedure for the bladed disc of an axial flow compressor rotor is illustrated by this sample problem. As explained in Section 1.15.3 the Design and Analysis steps are carried out only at the design operating point of the compressor bladed disc - the "as manufactured" structure being only "analyzed" at off-design operating points. The Design or Analysis mode of the Displacement Rigid Format 16 is selected by the PARAMETER SIGN. The present example uses the Design mode (SIGN = -1) of the rigid format.

The finite element model of a sector of the bladed disc is shown in Figure 1. The blade grid is specified in the Basic coordinate system located on the axis of rotation as shown in the figure. The hub is specified in a cylindrical coordinate system with the origin and the z-axis respectively coincident with the origin and the x-axis of the Basic system. A schematic of the aerodynamic model used is shown in Figure 2 wherein the aerodynamic mesh is generated by the intersection of 4 streamlines and 5 computing stations, three of which lie on the blade. Two additional computing stations have been used for the aerodynamic section (see Section 1.15.3.1), one each upstream and downstream of the blade to enable flow description in these regions. The NASTRAN deck for the use of the rigid format is listed in Figure 3.

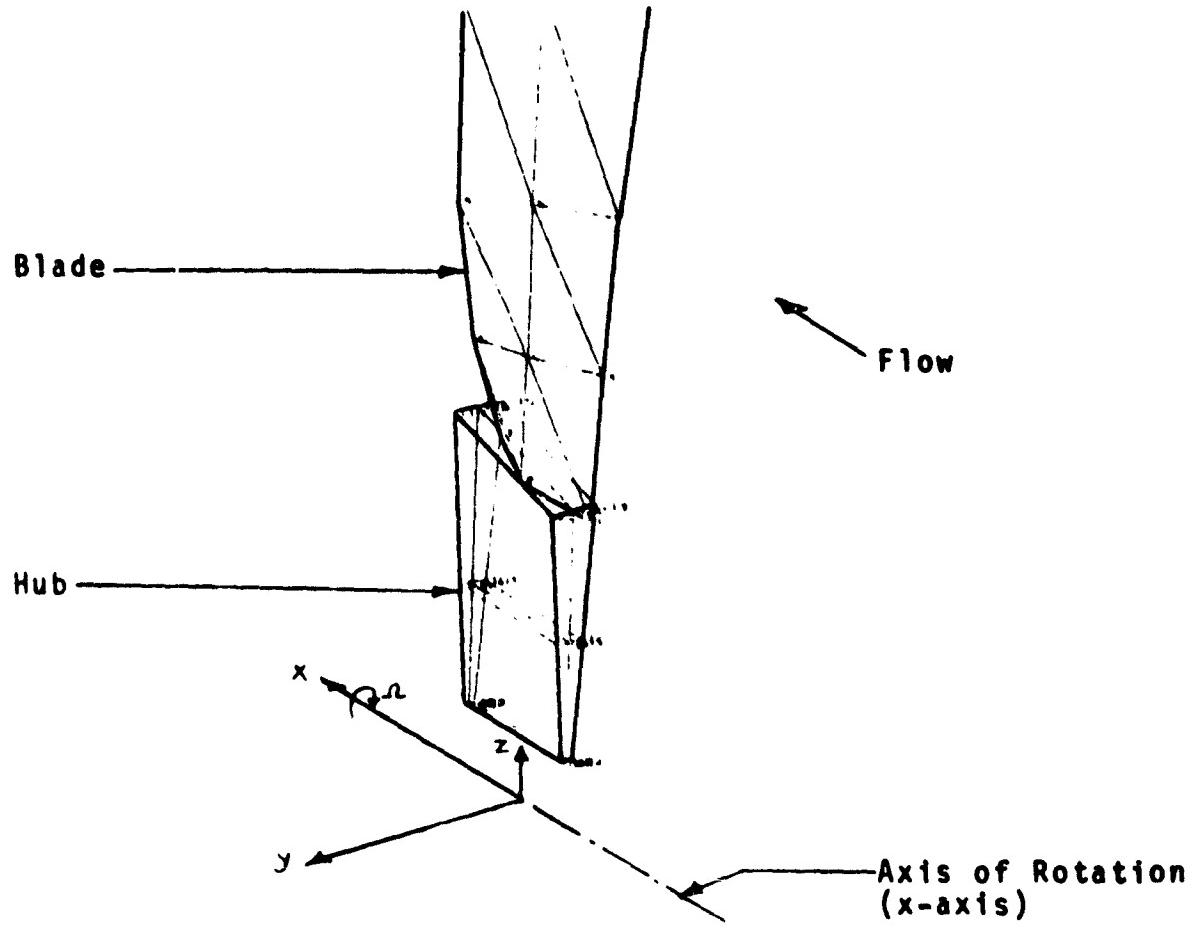


Figure 1. Finite Element Model of an Axial Flow Compressor Bladed Disc Sector, and the Basic Coordinate System

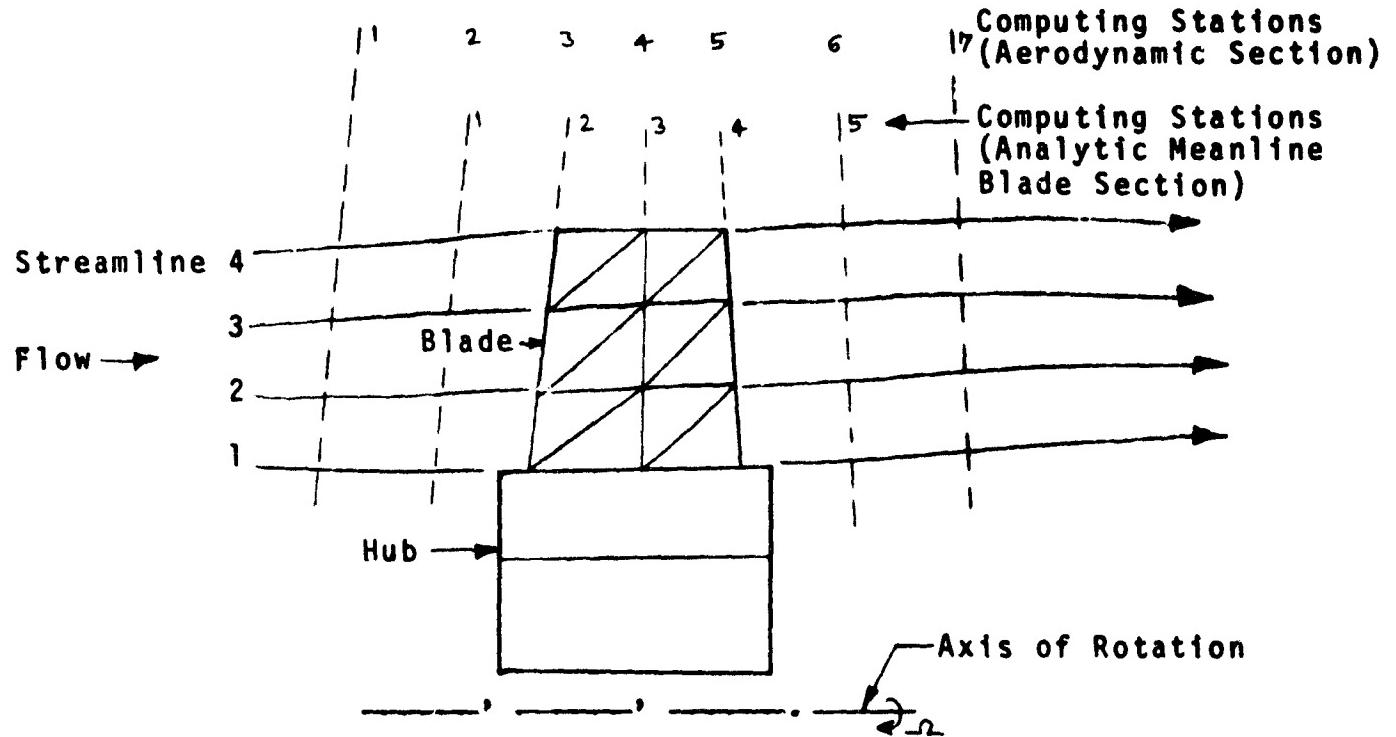


Figure 2. Aerodynamic Grid (See Section 1.15.3, User's Manual)

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NASTRAN EXECUTIVE CONTROL DECK ECHO

ID NASA - LEWIS
AP> DISPLACEMENT
SCL 15
TINE 10
CTAC 14
CEND

Figure 3. NASTRAN deck for Static Aeroelastic Design/Analysis

DESIGN RF BLADE
EASIER STAGE DESIGN DURING OPTIMIZATION

DESIGN RF BLADE

CCOUNT

CASE C CONTROL CHECK ECHO

1 TITLE = ASSEMBLED LEADS, GLADED SHROUNDED DISK ANALYSIS
2 SUBJECT = MAXIMIZE STAGE DESIGN CF ROTOR BLADE

3 LABEL = DESIGN OF BLADE

4 DC = 500

5 MPC = 600

6 LGEN = 1

7 DICO = ALL

8 SPCF = ALL

9 DLOAD = ALL

10 SDOES = 1

11 FPACE = ALL

12 SURFACE 1

13 LABEL = LINEAR SOLUTION CF ROTOR BLADE

14 SUBCASE 2

15 LABEL = NONLINEAR SOLUTION OF ROTOR BLADE

16 GPFGE = ALL

17 CUTOUT (PLT)

18 PLTTR AYSTPLT, MDEL 0.1

19 PAPER SIZE 12.0 X 11.5

20 SET 1 = ALL

21 CENTER RADIAL PROJECTION

22 MAXIMUM DEFORMATION 0.5

23 AXES X,Y,Z

24 VIEW 0.0,0.0,0.0

25 FIND SCALE, ORIGIN 1, SET 1

26 PLCT SET 1, ORIGIN 1, LABEL

27 AXES Y,Z,X

28 FIND SCALE, ORIGIN 2, SET 1

29 PLCT SET 1, ORIGIN 2, LABEL

30 AXES Z,Y,X

31 FIND SCALE, ORIGIN 3, SET 1

32 PLCT SET 1, ORIGIN 3, LABEL

33 AXES X,Y,Z

34 VFW 34.27, 23.17, 0.0

35 FIND SCALE, ORIGIN 4, SET 1

36 PLOT STATIC DEFORATION 0,

37 AXES Z,Y,X

38 VIEW 0.0,0.0,0.0

39 FIND SCALE, ORIGIN 5, SET 1

40 PLOT STATIC DEFORATION 0,

41 BEGIN BULK

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* USER INFORMATION MESSAGE 207, RULK DATA NOT SORTED,XSOPT WILL RE-CREATE CHECK.

NASA LEWIS PLANTED SPINNING FAN DESIGN OF FOTOR BLADE
EXHAUST SINGLE-STAGE DESIGN OF FOTOR BLADE

DESIGN OF PLATE

COUNT	C430	SORTED A UULK CATA ECHO
1-	CHEX1 1	101 4 103 5 104 6 108 7 113 8 115 9 116 10
2-	ECH1 116	120
3-	CHEX1 202	108 104 105 107 120 116
4-	ECH2 117	119
5-	CHEX1 203	121 123 124 128 101 103
6-	ECH3 104	108
7-	CHEX1 204	128 124 125/ 127 108 104
8-	ECH4 105	107
9-	C302C 1	0.0 0.0 0.0 1.0 0.0 0.0
10-	ECD1 0.	0.1 1.0 0.0 1.0 0.0 0.0
11-	CTRIAZ2 1	200 1 5 4
12-	CTRIAZ2 2	200 1 2 5
13-	CTRIAZ2 3	200 2 6 5
14-	CTRIAZ2 4	200 2 3 6
15-	CTRIAZ2 5	201 0 4 8 7
16-	CTRIAZ2 6	201 0 4 5 8
17-	CTRIAZ2 7	201 5 9 8
18-	CTRIAZ2 8	201 5 6 9
19-	CTRIAZ2 9	202 0 7 11 10
20-	CTRIAZ2 10	202 0 7 8 11
21-	CTRIAZ2 11	202 5 8 12 11
22-	CTRIAZ2 12	202 5 8 9 12
23-	DTI ALGO2 3	0 0 0 0 0 0
24-	SALG01 1	ENDREC
25-	DTI ALGO2 1	1 NASA LEWIS EXPERIMENTAL FAN
26-	DTI ALGO2 2	1 ENDREC
27-	DTI ALGO2 3	1 GRID GENERATOR ENDREC
28-	DTI ALGO2 4	4 5 2 4
29-	SALG01 2	2 1 ENDREC
30-	SALG02 2	4 1 ENDREC
31-	DTI ALGO2 5	4 384 100.0 1.0 0
32-	DTI ALGO2 6	2 0 ENDREC
33-	DTI ALGO2 7	-2.0 3.60 FACEFC
34-	DTI ALGO2 8	-2.0 10.04 ENCRFC
35-	DTI ALGO2 9	2.6 0 ENCRFC
36-	DTI ALGO2 10	5.5 0 ENDREC
37-	DTI ALGO2 11	7.4 0 ENDREC
38-	DTI ALGO2 12	10.04 0 ENDREC
39-	DTI ALGO2 13	4 1 ENDREC
40-	DTI ALGO2 14	-898 3.8 ENDREC
41-	DTI ALGO2 15	-763 5.5 ENDREC
42-	DTI ALGO2 16	-629 7.4 ENDREC
43-	DTI ALGO2 17	-424 10.0 ENDPEC
44-	DTI ALGO2 18	3.8 0 ENDREC
45-	DTI ALGO2 19	5.5 0 ENDPEC
46-	DTI ALGO2 20	7.4 0 ENDREC
47-	DTI ALGO2 21	10.0 ENDREC
48-	DTI ALGO2 22	ENDREC

NOVA LEWIS, PLATED MANUFACTURED DISK ANALYSIS
EXAPOLE SINGLE-STAGE DESIGN OF ROTOR BLADE

AY . 1 P-TAN . 1522 . 0000

DESIGN CF BLDG

CARD	CFN1	CFN2	ALGDA	CFN3	CFN4	CFN5	CFN6	CFN7	CFN8	CFN9	CFN10	CFN11	CFN12	CFN13	CFN14	CFN15	CFN16	CFN17	CFN18	CFN19	CFN20	CFN21	CFN22	CFN23	CFN24	CFN25	CFN26	CFN27	CFN28	CFN29	CFN30	CFN31	CFN32	CFN33	CFN34	CFN35	CFN36	CFN37	CFN38	CFN39	CFN40	CFN41	CFN42	CFN43	CFN44	CFN45	CFN46	CFN47	CFN48	CFN49	CFN50	CFN51	CFN52	CFN53	CFN54	CFN55	CFN56	CFN57	CFN58	CFN59	CFN60	CFN61	CFN62	CFN63	CFN64	CFN65	CFN66	CFN67	CFN68	CFN69	CFN70	CFN71	CFN72	CFN73	CFN74	CFN75	CFN76	CFN77	CFN78	CFN79	CFN80	CFN81	CFN82	CFN83	CFN84	CFN85	CFN86	CFN87	CFN88	CFN89	CFN90	CFN91	CFN92	CFN93	CFN94	CFN95	CFN96	CFN97	CFN98	CFN99	CFN100	CFN101	CFN102	CFN103	CFN104	CFN105	CFN106	CFN107	CFN108	CFN109	CFN110	CFN111	CFN112	CFN113	CFN114	CFN115	CFN116	CFN117	CFN118	CFN119	CFN120	CFN121	CFN122	CFN123	CFN124	CFN125	CFN126	CFN127	CFN128	CFN129	CFN130	CFN131	CFN132	CFN133	CFN134	CFN135	CFN136	CFN137	CFN138	CFN139	CFN140	CFN141	CFN142	CFN143	CFN144	CFN145	CFN146	CFN147	CFN148	CFN149	CFN150	CFN151	CFN152	CFN153	CFN154	CFN155	CFN156	CFN157	CFN158	CFN159	CFN160	CFN161	CFN162	CFN163	CFN164	CFN165	CFN166	CFN167	CFN168	CFN169	CFN170	CFN171	CFN172	CFN173	CFN174	CFN175	CFN176	CFN177	CFN178	CFN179	CFN180	CFN181	CFN182	CFN183	CFN184	CFN185	CFN186	CFN187	CFN188	CFN189	CFN190	CFN191	CFN192	CFN193	CFN194	CFN195	CFN196	CFN197	CFN198	CFN199	CFN200	CFN201	CFN202	CFN203	CFN204	CFN205	CFN206	CFN207	CFN208	CFN209	CFN210	CFN211	CFN212	CFN213	CFN214	CFN215	CFN216	CFN217	CFN218	CFN219	CFN220	CFN221	CFN222	CFN223	CFN224	CFN225	CFN226	CFN227	CFN228	CFN229	CFN230	CFN231	CFN232	CFN233	CFN234	CFN235	CFN236	CFN237	CFN238	CFN239	CFN240	CFN241	CFN242	CFN243	CFN244	CFN245	CFN246	CFN247	CFN248	CFN249	CFN250	CFN251	CFN252	CFN253	CFN254	CFN255	CFN256	CFN257	CFN258	CFN259	CFN260	CFN261	CFN262	CFN263	CFN264	CFN265	CFN266	CFN267	CFN268	CFN269	CFN270	CFN271	CFN272	CFN273	CFN274	CFN275	CFN276	CFN277	CFN278	CFN279	CFN280	CFN281	CFN282	CFN283	CFN284	CFN285	CFN286	CFN287	CFN288	CFN289	CFN290	CFN291	CFN292	CFN293	CFN294	CFN295	CFN296	CFN297	CFN298	CFN299	CFN300	CFN301	CFN302	CFN303	CFN304	CFN305	CFN306	CFN307	CFN308	CFN309	CFN310	CFN311	CFN312	CFN313	CFN314	CFN315	CFN316	CFN317	CFN318	CFN319	CFN320	CFN321	CFN322	CFN323	CFN324	CFN325	CFN326	CFN327	CFN328	CFN329	CFN330	CFN331	CFN332	CFN333	CFN334	CFN335	CFN336	CFN337	CFN338	CFN339	CFN340	CFN341	CFN342	CFN343	CFN344	CFN345	CFN346	CFN347	CFN348	CFN349	CFN350	CFN351	CFN352	CFN353	CFN354	CFN355	CFN356	CFN357	CFN358	CFN359	CFN360	CFN361	CFN362	CFN363	CFN364	CFN365	CFN366	CFN367	CFN368	CFN369	CFN370	CFN371	CFN372	CFN373	CFN374	CFN375	CFN376	CFN377	CFN378	CFN379	CFN380	CFN381	CFN382	CFN383	CFN384	CFN385	CFN386	CFN387	CFN388	CFN389	CFN390	CFN391	CFN392	CFN393	CFN394	CFN395	CFN396	CFN397	CFN398	CFN399	CFN400	CFN401	CFN402	CFN403	CFN404	CFN405	CFN406	CFN407	CFN408	CFN409	CFN410	CFN411	CFN412	CFN413	CFN414	CFN415	CFN416	CFN417	CFN418	CFN419	CFN420	CFN421	CFN422	CFN423	CFN424	CFN425	CFN426	CFN427	CFN428	CFN429	CFN430	CFN431	CFN432	CFN433	CFN434	CFN435	CFN436	CFN437	CFN438	CFN439	CFN440	CFN441	CFN442	CFN443	CFN444	CFN445	CFN446	CFN447	CFN448	CFN449	CFN450	CFN451	CFN452	CFN453	CFN454	CFN455	CFN456	CFN457	CFN458	CFN459	CFN460	CFN461	CFN462	CFN463	CFN464	CFN465	CFN466	CFN467	CFN468	CFN469	CFN470	CFN471	CFN472	CFN473	CFN474	CFN475	CFN476	CFN477	CFN478	CFN479	CFN480	CFN481	CFN482	CFN483	CFN484	CFN485	CFN486	CFN487	CFN488	CFN489	CFN490	CFN491	CFN492	CFN493	CFN494	CFN495	CFN496	CFN497	CFN498	CFN499	CFN500	CFN501	CFN502	CFN503	CFN504	CFN505	CFN506	CFN507	CFN508	CFN509	CFN510	CFN511	CFN512	CFN513	CFN514	CFN515	CFN516	CFN517	CFN518	CFN519	CFN520	CFN521	CFN522	CFN523	CFN524	CFN525	CFN526	CFN527	CFN528	CFN529	CFN530	CFN531	CFN532	CFN533	CFN534	CFN535	CFN536	CFN537	CFN538	CFN539	CFN540	CFN541	CFN542	CFN543	CFN544	CFN545	CFN546	CFN547	CFN548	CFN549	CFN550	CFN551	CFN552	CFN553	CFN554	CFN555	CFN556	CFN557	CFN558	CFN559	CFN560	CFN561	CFN562	CFN563	CFN564	CFN565	CFN566	CFN567	CFN568	CFN569	CFN570	CFN571	CFN572	CFN573	CFN574	CFN575	CFN576	CFN577	CFN578	CFN579	CFN580	CFN581	CFN582	CFN583	CFN584	CFN585	CFN586	CFN587	CFN588	CFN589	CFN590	CFN591	CFN592	CFN593	CFN594	CFN595	CFN596	CFN597	CFN598	CFN599	CFN600	CFN601	CFN602	CFN603	CFN604	CFN605	CFN606	CFN607	CFN608	CFN609	CFN610	CFN611	CFN612	CFN613	CFN614	CFN615	CFN616	CFN617	CFN618	CFN619	CFN620	CFN621	CFN622	CFN623	CFN624	CFN625	CFN626	CFN627	CFN628	CFN629	CFN630	CFN631	CFN632	CFN633	CFN634	CFN635	CFN636	CFN637	CFN638	CFN639	CFN640	CFN641	CFN642	CFN643	CFN644	CFN645	CFN646	CFN647	CFN648	CFN649	CFN650	CFN651	CFN652	CFN653	CFN654	CFN655	CFN656	CFN657	CFN658	CFN659	CFN660	CFN661	CFN662	CFN663	CFN664	CFN665	CFN666	CFN667	CFN668	CFN669	CFN670	CFN671	CFN672	CFN673	CFN674	CFN675	CFN676	CFN677	CFN678	CFN679	CFN680	CFN681	CFN682	CFN683	CFN684	CFN685	CFN686	CFN687	CFN688	CFN689	CFN690	CFN691	CFN692	CFN693	CFN694	CFN695	CFN696	CFN697	CFN698	CFN699	CFN700	CFN701	CFN702	CFN703	CFN704	CFN705	CFN706	CFN707	CFN708	CFN709	CFN710	CFN711	CFN712	CFN713	CFN714	CFN715	CFN716	CFN717	CFN718	CFN719	CFN720	CFN721	CFN722	CFN723	CFN724	CFN725	CFN726	CFN727	CFN728	CFN729	CFN730	CFN731	CFN732	CFN733	CFN734	CFN735	CFN736	CFN737	CFN738	CFN739	CFN740	CFN741	CFN742	CFN743	CFN744	CFN745	CFN746	CFN747	CFN748	CFN749	CFN750	CFN751	CFN752	CFN753	CFN754	CFN755	CFN756	CFN757	CFN758	CFN759	CFN760	CFN761	CFN762	CFN763	CFN764	CFN765	CFN766	CFN767	CFN768	CFN769	CFN770	CFN771	CFN772	CFN773	CFN774	CFN775	CFN776	CFN777	CFN778	CFN779	CFN780	CFN781	CFN782	CFN783	CFN784	CFN785	CFN786	CFN787	CFN788	CFN789	CFN790	CFN791	CFN792	CFN793	CFN794	CFN795	CFN796	CFN797	CFN798	CFN799	CFN800	CFN801	CFN802	CFN803	CFN804	CFN805	CFN806	CFN807	CFN808	CFN809	CFN810	CFN811	CFN812	CFN813	CFN814	CFN815	CFN816	CFN817	CFN818	CFN819	CFN820	CFN821	CFN822	CFN823	CFN824	CFN825	CFN826	CFN827	CFN828	CFN829	CFN830	CFN831	CFN832	CFN833	CFN834	CFN835	CFN836	CFN837	CFN838	CFN839	CFN840	CFN841	CFN842	CFN843	CFN844	CFN845	CFN846	CFN847	CFN848	CFN849	CFN850	CFN851	CFN852	CFN853	CFN854	CFN855	CFN856	CFN857	CFN858	CFN859	CFN860	CFN861	CFN862	CFN863	CFN864	CFN865	CFN866	CFN867	CFN868	CFN869	CFN870	CFN871	CFN872	CFN873	CFN874	CFN875	CFN876	CFN877	CFN878	CFN879	CFN880	CFN881	CFN882	CFN883	CFN884	CFN885	CFN886	CFN887	CFN888	CFN889	CFN890	CFN891	CFN892	CFN893	CFN894	CFN895	CFN896	CFN897	CFN898	CFN899	CFN900	CFN901	CFN902	CFN903	CFN904	CFN905	CFN906	CFN907	CFN908	CFN909	CFN910	CFN911	CFN912	CFN913	CFN914	CFN915	CFN916	CFN917	CFN918	CFN919	CFN920	CFN921	CFN922	CFN923	CFN924	CFN925	CFN926	CFN927	CFN928	CFN929	CFN930	CFN931	CFN932	CFN933	CFN934	CFN935	CFN936	CFN937	CFN938	CFN939	CFN940	CFN941	CFN942	CFN943	CFN944	CFN945	CFN946	CFN947	CFN948	CFN949	CFN950	CFN951	CFN952	CFN953	CFN954	CFN955	CFN956	CFN957	CFN958	CFN959	CFN960	CFN961	CFN962	CFN963	CFN964	CFN965	CFN966	CFN967	CFN968	CFN969	CFN970	CFN971	CFN972	CFN973	CFN974	CFN975	CFN976	CFN977	CFN978	CFN979	CFN980	CFN981	CFN982	CFN983	CFN984	CFN985	CFN986	CFN987	CFN988	CFN989	CFN990	CFN991	CFN992	CFN993	CFN994	CFN995	CFN996	CFN997	CFN998	CFN999	CFN1000
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CARD COUNT
 151- DTI 209 4.0 ENDREC
 152- DTI 209 4.0 ENDREC
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 154- DTI 209 3.25 ENDREC
 155- DTI 209 0 ENDREC
 156- DTI 209 4.0 ENDREC
 157- DTI 209 10.0 ENDREC
 158- DTI 209 0 ENDREC
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 178- GRID 1 -0.8980 -0.2722 3.7502
 179- GRID 2 0 .0522 3.9556
 180- GRID 3 0.8980 -0.2459 4.1926
 181- GRID 4 -0.7630 -0.5004 5.4772
 182- GRID 5 0 .0205 5.5000
 183- GRID 6 0.7630 -0.2342 5.4950
 184- GRID 7 -0.6200 -0.1454 7.3620
 185- GRID 8 0 .0131 7.4000
 186- GRID 9 0.6290 -0.6365 7.3725
 187- GRID 10 -0.4240 -0.5230 9.9564
 188- GRID 11 0 -0.0221 15.0000
 189- GRID 12 -4.240 .7556 9.9711
 190- GRID 13 1 2.375 4.166 -0.567 1
 191- GRID 14 1 2.375 4.166 -0.567 1
 192- GRID 15 1 2.375 4.166 -0.567 1
 193- GRID 16 1 2.375 4.166 -0.567 1
 194- GRID 17 1 2.375 4.166 -0.567 1
 195- GRID 18 1 2.375 4.166 -0.567 1
 196- GRID 19 1 2.375 4.166 -0.567 1
 197- GRID 20 1 2.375 4.166 -0.567 1
 198- GRID 21 1 2.375 4.166 -0.567 1
 199- GRID 22 1 2.375 4.166 -0.567 1
 200- GRID 23 1 2.375 4.166 -0.567 1
 201- GRID 24 1 2.375 4.166 -0.567 1
 202- GRID 25 1 2.375 4.166 -0.567 1
 203- GRID 26 1 2.375 4.166 -0.567 1
 204- GRID 27 1 2.375 4.166 -0.567 1
 205- GRID 28 1 2.375 4.166 -0.567 1
 206- GRID 29 1 2.375 4.166 -0.567 1
 207- GRID 30 1 2.375 4.166 -0.567 1
 208- GRID 31 1 2.375 4.166 -0.567 1
 209- GRID 32 1 2.375 4.166 -0.567 1
 210- GRID 33 1 2.375 4.166 -0.567 1
 211- GRID 34 1 2.375 4.166 -0.567 1
 212- GRID 35 1 2.375 4.166 -0.567 1
 213- GRID 36 1 2.375 4.166 -0.567 1
 214- GRID 37 1 2.375 4.166 -0.567 1
 215- GRID 38 1 2.375 4.166 -0.567 1
 216- GRID 39 1 2.375 4.166 -0.567 1
 217- GRID 40 1 2.375 4.166 -0.567 1
 218- GRID 41 1 2.375 4.166 -0.567 1
 219- GRID 42 1 2.375 4.166 -0.567 1
 220- GRID 43 1 2.375 4.166 -0.567 1

COUNT	CAAC	STREAML-1	STREAML-2	STREAML-3	STREAML-4	STREAML-5	STREAML-6	STREAML-7	STREAML-8	STREAML-9	STREAML-10
251-	PAGAN	1	2	0	0	0	0	0	0	0	0
252-	SACAU	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000
253-	PTPIA2	2000	1	1	1	1	1	1	1	1	1
254-	PTQIA2	2005									
255-	PTRA2	2010	1	1	1	1	1	1	1	1	1
256-	PTPIA2	2015	1	1	1	1	1	1	1	1	1
257-	PTPIA2	2020	1	1	1	1	1	1	1	1	1
258-	PTPIA2	2025	1	1	1	1	1	1	1	1	1
259-	PEFCCE	1	0	0	0	0	0	0	0	0	0
260-	PECI	500	23	121	123	124	125	126	127	128	129
261-	PECI	500	45	7	10	12	12	12	12	12	12
262-	ECI	500	456	101	103	104	105	107	108	109	110
263-	ECI	500	456	113	115	116	117	118	119	120	121
264-	ECI	500	456	121	123	124	125	127	128	129	130
265-	STREAML11	1	1	1	1	1	1	1	1	1	1
266-	STREAML12	4	4	4	4	4	4	4	4	4	4
267-	STREAML13	7	7	7	7	7	7	7	7	7	7
268-	STREAML14	10	10	10	10	10	10	10	10	10	10
	ENRCATA										

The Executive Control Deck consists of cards from ID to CEND. SOL 16 and APP Displacement are used for the Steady Aerothermoelastic Design/Analysis problem. CPU time (in minutes) is estimated on the TIME card. DIAG (optional) is used to request diagnostic output.

The Case Control Deck is used to select the boundary conditions imposed on, and the loads applied to the structure. The extent and the form of the output desired is also selected in this deck. In this problem, SPC set 500 is used to restrain the hub-shaft attachment degrees of freedom from moving in the axial and tangential direction. MPC set 600 is used to define the blade-hub attachment and the relative motion of the corresponding grid points on the two sides of the cyclic sector. Two subcases must be defined for this rigid format. Subcase 1 is for the linear solution based on the elastic stiffness while Subcase 2 solution includes the differential stiffness effects. The OUTPUT (PLOT) packet requests the plots, and is explained in Section 4. of the User's Manual.

The blade is idealized by 12 CTRIA2 plate elements while 4 CHEXA1 solid elements are used to model the hub. The aerodynamic data describing the blade geometry (blade angle, chords, stagger angles etc.) and the operating conditions (flow rate, speed, losses etc.) are specified in the ALGDB data block input via the DTI bulk data cards. The geometry, material and constraint bulk data are as discussed in previous sections of this manual. Parameters APRESS = 1 and ATEMP = 1 enable the inclusion of the aerodynamic pressure and thermal loads. FXC00R, FYC00R

and FZC00R parameters each equal to 0.3 indicate that, in this design example, three tenths of the displacements obtained (both linear and non-linear) are used to redefine the blade geometry. Parameters IPRTCF = 1 and IPRTCI = 1 are used for a detailed printout from the ALG module upon final and initial entries. IPRTCL = 0 requests a summary from the ALG module during the differential stiffness loop (see Section 18 of the Theoretical Manual). PGE0M = 3 causes the GRID, CTRIA2, PTRIA2 and DTI bulk data cards to be punched out during the final pass through the ALG module. These cards represent the final blade geometry and the operating conditions. Parameter STREAML = -1 suppresses the output of STREAML1 and STREAML2 bulk data cards, while Z0RIGN = 0 only is currently permitted. STREAML1 cards identify the grid points defining the blade.

Results are presented in the Demonstration Problems Manual.

1.15.5 Modal, Flutter & Subcritical Roots Analyses

Cyclic symmetric flow is assumed while analyzing the turbomachinery rotor/stator. Due to rotational cyclic symmetry, only one-bladed disc sector is modeled. The harmonic number dependent cyclic normal modal analysis of such structures is described in Section 1.12 of the User's Manual. In the present development, the results of the normal modes analysis using cyclic symmetry have been appropriately integrated with unsteady cascade aerodynamic theories and the existing k-method of modal flutter analysis. The Mach number parameter has been conveniently replaced by the interblade phase angle parameter for blade flutter problems. The discussion that follows is to bring out the features pertinent to bladed disc analysis.

In a compressor or turbine, an operating point implies an equilibrium of flow properties such as density, velocity, Mach number, flow angle, etc., that vary across the blade span. Blade properties like the blade angles, stagger angle, chord, etc., also, in general, change from the blade root to the tip. The resulting spanwise variation in the local reduced frequency and the relative Mach number must be accounted for in estimating the chordwise generalized aerodynamic forces per unit span at each streamline. Integration of these forces over the blade span yields the blade generalized aerodynamic force matrix. In order to nondimensionalize this matrix, the flow and blade properties at a referenced streamline are used. The reference streamline number, IREF, is specified on a PARAM bulk data card.

Since the relative Mach number varies along the blade span, necessitating the use of either the subsonic or supersonic cascade theories, parameters MAXMACH and MINMACH are used respectively to specify the upper and lower limits below and above which the subsonic and supersonic unsteady cascade theories are applicable. For streamlines with relative Mach numbers between the limits MAXMACH and MINMACH, linear interpolation is used. No transonic cascade theories have been incorporated.

It should be noted that for a given interblade phase angle and reference reduced frequency, chordwise generalized aerodynamic matrices corresponding to local spacing, stagger and Mach number at the selected operating point will be generated for each streamline on the blade. This is an expensive operation and should be carefully controlled to reduce the computational work. The aerodynamic matrices are, therefore, computed at a few interblade phase angles and reduced frequencies, and interpolated for others. These parameters are selected on the MKAERO1 and MKAERO2 bulk data cards. Matrix interpolation is an automatic feature of Rigid Format Aero 9. Additional aerodynamic matrices may be generated and appended to the previous group on restart with new MKAERO1 cards, provided the rest of the data used for the matrix calculation remain unaltered.

To save further computational time, the chordwise generalized aerodynamic matrices are first computed for "aerodynamic modes" (see the Theoretical Manual, Section). The aerodynamic matrices for chordwise structural modes are then determined from bilinear transformations along each streamline prior to the spanwise integration to obtain the complete blade generalized aerodynamic matrix. This permits a change in the structural mode shapes of the same or a different harmonic number to be included in the flutter analysis without having to recompute the modal aerodynamic matrices for aerodynamic modes. This can be achieved by appropriate ALTERS to the Rigid Format.

For non-zero harmonic numbers, the normal modes analysis using cyclic symmetry results in both "sine" and "cosine" mode shapes (Section 1.12). The BCD value of the parameter MTYPE on a PARAM bulk data card selects the type of mode shapes to be used in flutter calculations. It is immaterial which is selected.

The method of flutter analysis is specified on the FLUTTER bulk data card. The FLUTTER card is selected by an FMETHØD card. At the present time, only the k-method of flutter analysis is available. This allows looping through three sets

of parameters: density ratio (ρ/ρ_{ref} ; ρ_{ref} is given on AERØ card); interblade phase angle (σ); and reduced frequency, ($k.$) For example, if the user specifies two values of each, there will be eight loops in the following order.

<u>LOOP</u>	<u>DENS</u>	<u>σ</u>	<u>RFREQ</u>
1	1	1	1
2	2	1	1
3	1	1	2
4	2	1	2
5	1	2	1
6	2	2	1
7	1	2	2
8	2	2	2

Values for the parameters are listed on FLFACT bulk data cards. Usually, one or two of the parameters will have only a single value.

A parameter VREF may be used to scale the output velocity. This can be used to convert from consistent units (e.g., in/sec) to any units the user may desire (e.g., mph), determined from $V_{out} = V/V_{REF}$. Another use of this parameter is to compute flutter index, by choosing $V_{REF} = b\omega_0 \sqrt{\mu}$.

If physical output (grid point deflections or element forces, plots, etc.) is desired rather than modal amplitudes, this data recovery can be made upon a user selected subset of the cases. The selection is based upon the velocity; the method is discussed in Section 3.23.3.

i-15.6 Sample Problem
(To be written)

USER'S MANUAL UPDATES

1.15.6 Sample Problem

The problem of determining the complete, unstalled flutter boundaries of a compressor or turbine bladed disc involves each member set of an appropriate whole series of harmonic families of modes of the cyclically symmetric bladed discs, and effects of interblade phase angle, over an adequate set of operating points (flow rates, speeds, pressure ratios, implied Mach numbers, etc.). This sample problem, therefore, is only to illustrate the procedure to obtain typical data leading to the definition of flutter boundaries.

The finite element model of the compressor bladed disc sector is shown in Figure 1. The aerodynamic model (see Section 1.15.2) with 4 streamlines and 3 computing stations is shown in Figure 2. The first four of the zeroth harmonic family of natural modes and frequencies are chosen for flutter investigation via the PARAMeters LMODES = 4 and KINDEX = 0. Operating point conditions of 73.15 lb m/sec flow rate, 16043 rpm, and 1.84 total pressure ratio are selected so as to demonstrate the use of the total stiffness matrix, for cyclic modal analysis, saved from the Static Aerothermoelastic Analysis at this operating point (see Demonstration Manual examples 9-5-1 and 16-1). For this, the Parameter KGGIN is set equal to 1. The k-method of flutter analysis is used which is the only method currently permitted. The NASTRAN deck used is listed in Figure 3.

The Executive Control Deck, cards ID through CEND, selects the Cyclic Modal Flutter Analysis Rigid Format via the S_{DL} 9 and APP AER0 cards. An estimated CPU TIME of 20 minutes is indicated for this example. The DIAG 14 card is optional and lists the Rigid Format.

The Case Control Deck is used to select constraints, methods and output. In this problem, SPC set 500 is used to constrain the hub-shaft attachment degrees of freedom to move only in the radial direction. MPC set 600 is used to define the blade-hub connection. A METH₀D card must select an EIGR bulk data card for real eigenvalue analysis. An FMETH₀D card must be used to select a FLUTTER data card for flutter analysis. A CMETH₀D card must select an EIGC data card for complex eigenvalue extraction. For a flutter summary printout, the parameter PRINT is set to YESB. The XYPAPERPL₀T request shown will plot V-g and V-f split frame "plots" on the printer output. To produce plots, it is necessary to specify a plotter, request a plot tape, and specify XYPAPERPL₀T VG. The "curves" refer to the loops of the flutter analysis, and in this example the 9 loops have been arranged with 3 loops to each frame.

The blade and the hub are respectively modeled by 12 CTRIA2 and 4 CHEXA1 elements. The geometry, material and constraint bulk data are as discussed in previous sections of this manual, and there are no special rules for aeroelastic flutter analysis. CYJ₀IN data card specifies the pairs of corresponding grid points on the two sides of the cyclic sector. INV method of real eigenvalue extraction is selected on an EIGR card wherein five mode shapes and frequencies are requested.

Of these, the first four (Parameter LMODES = 4) modes are used to form the modal flutter equations. The AERØ bulk data card is used to specify the reference chord and reference density. For bladed disc flutter analysis, the other two parameters on the AERØ card are of no significance. The MKAERØ1 data card causes the aerodynamic matrices to be computed for three interblade phase angle-reduced frequency pairs, i.e. ($\sigma = 180^\circ$, $k = 0.3$), (180° , 0.7) and (180° , 1.0).

The FLUTTER bulk data card selects the presently permitted k-method of flutter analysis and refers to the FFACT cards specifying density ratios, interblade phase angles, and reduced frequencies. The analysis loops through all combinations of densities, interblade phase angles and reduced frequencies, with density on the inner loop and interblade phase angle on the outermost loop. In this example, 3 density ratios, 1 interblade phase angle and 3 reduced frequencies (on FFACT cards) result in ($3 \times 1 \times 3 =$) 9 loops. Both linear and surface splines are available for interpolation of aerodynamic matrices to intermediate values of interblade phase angle and reduced frequency. The EIGC card is required and the HESS method is used. The number of complex eigenvectors to be extracted must be specified, and will usually agree with the number of modes saved for output specified on the FLUTTER data card.

For bladed discs, STREAML1 and STREAML2 data cards are required. The grid points on each streamline on the blade are identified on the STREAML1 card. The flow and blade geometry is specified for each streamline on the STREAML2 cards. It should be noted that at least 3 streamlines per blade (including

the root and the tip) and 3 grid points per streamline must be selected for cyclic modal flutter analysis.

Results are presented in the Demonstration Problems Manual.

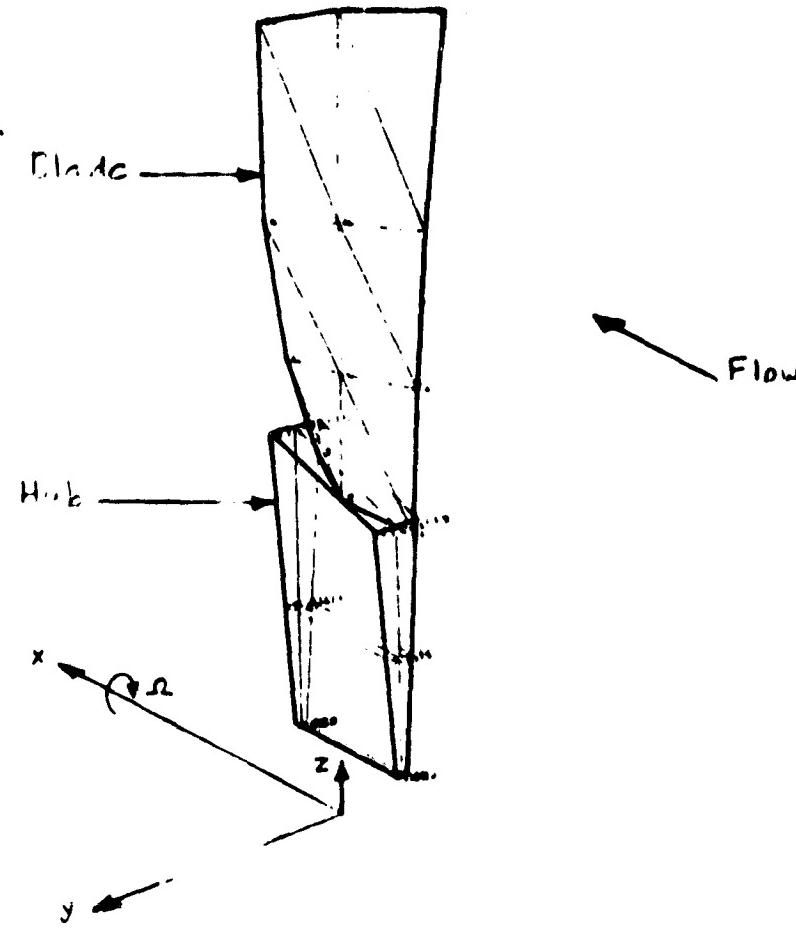


FIGURE 1. FINITE ELEMENT MODEL

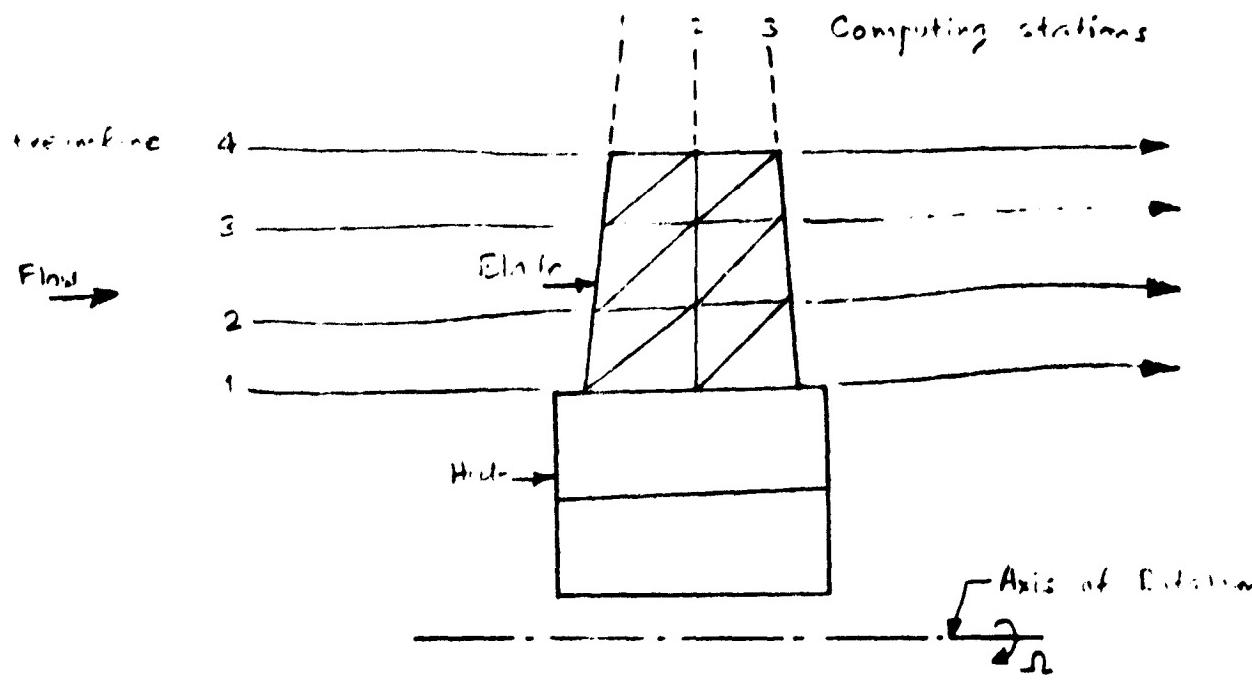


FIGURE 2. AERODYNAMIC MODEL

NASTRAN EXECUTIVE CONTROL DECK, ECHO

IN NASA - LEWIS
EPP BEFC
SCL 5
TIME 20
FLAG 14
CEND

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Figure 3. NASTRAN DECK FOR CYCLIC MODAL FLUTTER ANALYSIS OF BLADED DISCS

CASE CONTROL LINES

CCOUNT

1 TITLE = NASA LEAPS. BLADED SWAGED DISK ANALYSIS
2 SURTITLE = EXAMINE SINGLE-STAGE DESIGN OF FOTIA PLATE
3 UPREL = AERORELSTIC FLUTTER ANALYSIS
4 FMETHOD = 30
5 SPC = 500
6 SPC = EGG
7 NTHIN = 12
8 CVENTD = 20
9 DISE = ALL
10 PIPELINE
11 XTITLE = V=LCITY-V
12 YTITLE = C=MEANG-C
13 ZTITLE = FREQUENCY-E
14 XADDEDPNT V, C, / 1(G,E) * 4(G,F) * 7(G,F) / 2(G,F) * 5(G,F) * 8(G,F) /
15 3(G,F) * 6(G,F) * 9(G,F)
16 BEGIN BULK

AEROMECHANICAL FLUTTER ANALYSIS

FOR AEROMECHANICAL FLUTTER ANALYSIS
FOR AEROMECHANICAL FLUTTER ANALYSIS

SORT FOR BULK DATA ECHO

CARD COUNT	1	2	3	4	5	6	7	8	9	10
1- ECH1	0	1.0364	1.86958	1.5076	..	..	..	..	..	..
2- CHEXA1	201	1	101	103	104	108	113	115	115	ECH1
3- ECH1	113	120	..	..	..	..	..	..	..	..
4- FHEXA1	202	1	108	104	105	107	120	116	116	ECH2
5- ECH2	117	118	..	..	..	..	..	..	..	..
6- CHEXA1	203	1	121	123	124	128	101	103	103	ECH3
7- ECH3	104	108	..	..	..	..	..	..	..	..
8- CHEXA1	204	1	128	124	125	127	108	104	104	ECH4
9- ECH4	135	137	..	..	..	..	..	..	..	..
10- CNOB20	1	..	..	..	..	..	..	..	..	..
11- EC01	0	2.	1.	1.	1.	1.	..	..	..	..
12- CT2IA2	1	2000	1	5	4	..	..	..	..	..
13- CT2IA2	2	2000	1	2	5	..	..	..	..	..
14- CT2IA2	3	2005	2	6	5	..	..	..	..	..
15- CT2IA2	4	2005	2	3	6	..	..	..	..	..
16- CTRIA2	5	2010	4	8	7	..	..	..	..	..
17- CT2IA2	6	2010	4	5	8	..	..	..	..	..
18- CT2IA2	7	2015	5	9	8	..	..	..	..	..
19- CT2IA2	8	2015	5	6	9	..	..	..	..	..
20- CT2IA2	9	2020	7	11	10	..	..	..	..	..
21- CT2IA2	10	2020	7	8	11	..	..	..	..	..
22- CT2IA2	11	2025	8	12	11	..	..	..	..	..
23- CT2IA2	12	2025	8	9	12	..	..	..	..	..
24- CYJCIN	1	121	101	113	123	103	115	115	115	..
25- CYJCIV	2	127	107	119	125	105	117	117	117	..
26- FIGC	20	HESS	MAX	..	..	..	..	..	..	..
27- FIGC20	10	INV	2000.0	2000.0	8	5	3	3	3	..
28- FIGC20	MAX	..	..	..	..	..	..	..	..	..
29- FLFACT	1	0.059164	-1.18328	-1.77452	..	..	..	..	..	..
30- FLFACT	2	180.0	..	..	..	..	..	..	..	..
31- FLFACT	3	..	..	..	..	..	..	..	..	..
32- FLITTER	30	K	1	2	3	..	..	..	..	..
33- FLITTER	30	K	1	2	3	L	..	..	..	..
34- GR10	1	..	-0.8979	-0.2814	3.7712	..	..	..	..	..
35- GR10	2	..	..	..	..	..	..	..	..	..
36- GR10	3	..	..	..	..	..	..	..	..	..
37- GR10	4	..	-0.7736	-0.4744	5.4412	..	..	..	..	..
38- GR10	5	..	..	..	..	..	..	..	..	..
39- GR10	6	..	-0.0031	0.3228	5.5023	..	..	..	..	..
40- GR10	7	..	..	..	..	..	..	..	..	..
41- GR10	8	..	-0.6646	-0.7062	7.2062	..	..	..	..	..
42- GR10	9	..	-0.3157	0.0164	7.4058	..	..	..	..	..
43- GR10	10	..	..	..	..	..	..	..	..	..
44- GR10	11	..	-0.5237	-1.1552	9.8520	..	..	..	..	..
45- GR10	12	..	-0.3220	-0.6656	10.0079
46- GR10	101
47- GR10	102
48- GR10	104
49- GR10	105

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FLUTTER QUALITY

S O R T F D B L C E A I A E U H U

E9C	C117	1	2	•	3	•	4	•	5	•	6	•	7	•	8	•	9	•	10
S1-	C119	113	1	1	2.375	.0	2.375	.0	-5.5E7	1	-5.5E7	1	-5.5E7	1	-5.5E7	1	-5.5E7	1	-5.5E7
E2-	C119	115	1	1	3.932	4.186	4.186	4.186	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7
E3-	C119	116	1	1	4.539	4.186	4.186	4.186	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7
E4-	C119	117	1	1	4.539	4.186	4.186	4.186	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7
E5-	C119	119	1	1	2.532	-4.186	-4.186	-4.186	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7
E6-	C119	122	1	1	3.732	.0	3.732	.0	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7	1	-3.5E7
E7-	C119	121	1	1	-905	4.186	4.186	4.186	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7
E8-	C119	123	1	1	-905	4.186	4.186	4.186	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7	1	-0.5E7
E9-	C119	124	1	1	-905	0	0	0	-537	1	-537	1	-537	1	-537	1	-537	1	-537
E10-	C119	125	1	1	-905	-4.186	-4.186	-4.186	-587	1	-587	1	-587	1	-587	1	-587	1	-587
E11-	C119	127	1	1	-905	-4.186	-4.186	-4.186	-587	1	-587	1	-587	1	-587	1	-587	1	-587
E12-	C119	128	1	1	-905	0	0	0	-537	1	-537	1	-537	1	-537	1	-537	1	-537
E13-	M411	1	31.0E6						7.3CCE-4										
E14-	C121	120.0																	
E15-	C121	0.3	0.7	1.0															
E16-	PPC	603	1	1															
E17-	PPC	603	1	2															
E18-	PPC	603	1	3															
E19-	PPC	603	1	4															
E20-	PPC	603	1	5															
E21-	PPC	603	1	6															
E22-	PPC	603	3	1															
E23-	PPC	603	3	2															
E24-	PPC	603	3	3															
E25-	PPC	603	3	4															
E26-	PPC	603	3	5															
E27-	PPC	603	3	6															
E28-	PPC	503	1	1															
E29-	PPC	603	1	16															
E30-	PPC	603	1	16															
E31-	MPC	603	1	16															
E32-	MPC	603	1	16															
E33-	MPC	603	1	16															
E34-	MPC	603	1	16															
E35-	MPC	603	1	16															
E36-	MPC	603	1	16															
E37-	MPC	603	1	16															
E38-	MPC	603	1	16															
E39-	MPC	603	1	16															
E40-	MPC	603	1	16															
E41-	MPC	603	1	16															
E42-	MPC	603	1	16															
E43-	MPC	603	1	16															
E44-	MPC	603	1	16															
E45-	MPC	603	1	16															
E46-	MPC	603	1	16															
E47-	MPC	603	1	16															
E48-	MPC	603	1	16															
E49-	MPC	603	1	16															
E50-	MPC	603	1	16															
E51-	MPC	603	1	16															
E52-	MPC	603	1	16															
E53-	MPC	603	1	16															
E54-	MPC	603	1	16															
E55-	MPC	603	1	16															
E56-	MPC	603	1	16															
E57-	MPC	603	1	16															
E58-	MPC	603	1	16															
E59-	MPC	603	1	16															
E60-	MPC	603	1	16															
E61-	MPC	603	1	16															
E62-	MPC	603	1	16															
E63-	MPC	603	1	16															
E64-	MPC	603	1	16															
E65-	MPC	603	1	16															
E66-	MPC	603	1	16															
E67-	MPC	603	1	16															
E68-	MPC	603	1	16															
E69-	MPC	603	1	16															
E70-	MPC	603	1	16															
E71-	MPC	603	1	16															
E72-	MPC	603	1	16															
E73-	MPC	603	1	16															
E74-	MPC	603	1	16															
E75-	MPC	603	1	16															
E76-	MPC	603	1	16															
E77-	MPC	603	1	16															
E78-	MPC	603	1	16															
E79-	MPC	603	1	16															
E80-	MPC	603	1	16															
E81-	MPC	603	1	16															
E82-	MPC	603	1	16															
E83-	MPC	603	1	16															
E84-	MPC	603	1	16															
E85-	MPC	603	1	16															
E86-	MPC	603	1	16															
E87-	MPC	603	1	16															
E88-	MPC	603	1	16															
E89-	MPC	603	1	16															
E90-	MPC	603	1	16															
E91-	MPC	603	1	16															
E92-	MPC	603	1	16															
E93-	MPC	603	1	16															
E94-	MPC	603	1	16															
E95-	MPC	603	1	16															
E96-	MPC	603	1	16															
E97-	MPC	603	1	16															
E98-	MPC	603	1	16															
E99-	MPC	603	1	16															
E100-	MPC	603	1	16															

LARGE LENGTH PLANE² SURGED DISK ANALYSIS
TABLE SINGLE-STAGE DESIGN OF PORTER BLADE

INELASTIC FLUTTER ANALYSIS

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CARD	CCM#T	1	2	3	4	5	6	7	8	9	10
101-	SPC1	500	23	121	123	124	125	127	128	128	128
102-	SPC1	500	45	7	10	12					
103-	SPC1	500	456	101	103	104	105	107	108		
104-	SPC1	500	456	113	115	116	117	119	120		
105-	SPC1	500	456	121	123	124	125	127	128		
106-	STREAML1	1	2	3	4	5	6				
107-	STREAML12	4	5	6							
108-	STREAML13	7	8	9							
109-	STREAML14	10	11	12							
110-	STREAML21	7	2.739	1.7560	3.98420	58217	656846	069472	ESTRL 1		
111-	ESTRL 1	719.0	47.423								
112-	STREAML22	3	23.534	1	344	6.06853	88674	524388	066610	ESTRL 2	
113-	ESTPL 2	1014.2	55.107								
114-	STREAML23	3	44.697	1.86619	8.07620	1.18010	1.153666	064685	ESTPL 3		
115-	ESTRL 3	1283.1	60.380								
116-	STREAML24	3	62.028	1.96558	9.92791	1.45067	1.502276	059201	ESTRL 4		
117-	ESTOL 4	1592.6	60.687								
	ENDDATA										

NASTRAN DATA DECK

TIME K Required.

K -- Maximum allowable execution time in minutes.

SOL K1[,K1] or SOL An [,K1] Required when using a rigid format (see Section 3.1 for available options).

K1 -- Solution number of Rigid Format (see table below and Section 3.1).

K1 -- Subset numbers for solution K1, default value = 0. Multiple subsets may be selected by using multiple integers separated by commas.

An -- Name of Rigid Format (see table below)

Displacement Approach Rigid Formats

<u>K1</u>	<u>An</u>
1	STATICS
2	INERTIA RELIEF
3	MODES or NORMAL MODES or REAL EIGENVALUES
4	DIFFERENTIAL STIFFNESS
5	BUCKLING
6	PIECEWISE LINEAR
7	DIRECT COMPLEX EIGENVALUES
8	DIRECT FREQUENCY RESPONSE
9	DIRECT TRANSIENT RESPONSE
10	MODAL COMPLEX EIGENVALUES
11	MODAL FREQUENCY RESPONSE
12	MODAL TRANSIENT RESPONSE
13	NORMAL MODES ANALYSIS WITH DIFFERENTIAL STIFFNESS
14	STATICS CYCLIC SYMMETRY
15	MODES CYCLIC SYMMETRY
16	STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

Heat Transfer Approach Rigid Formats

<u>K1</u>	<u>An</u>
1	STATICS
3	STEADY STATE
9	TRANSIENT

Aeroelastic Approach Rigid Format

<u>K1</u>	<u>An</u>
9	COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS
10	MODAL FLUTTER ANALYSIS

Subset Numbers

1. Delete loop control.
2. Delete mode acceleration method of data recovery (modal transient and modal frequency response).
3. Combine subsets 1 and 2.
4. Check all structural and aerodynamic data without execution of the aeroelastic problem.

5. Check only the aerodynamic data without execution of the aeroelastic problem.
6. Delete checkpoint instructions.
7. Delete structure plotting and X-Y plotting.
8. Delete Grid Point Weight Generator.
9. Delete fully stressed design (static analysis).

CASE CONTROL DECK

The following cards are used to make output requests for the calculated response of components in the SOLUTION set (components in the direct or modal formulation of the general K system) for dynamics problems:

1. SACCELERATION - requests the acceleration of the independent components for a selected set of points or modal coordinates.
2. SDISPLACEMENT - requests the displacements of the independent components for a selected set of points or modal coordinates or the temperatures of the independent components for a selected set of points in heat transfer.
3. SVELCITY - requests the velocities of the independent components for a selected set of points or nodal coordinates or the change in temperature with respect to time of the independent components for a selected set of points in heat transfer.
4. NLOAD - requests the nonlinear loads for a selected set of physical points (grid points and extra points introduced for dynamic analysis) in transient response problems.

The following cards are used to make output requests for stresses and forces, as well as the calculated response of degrees of freedom used in the model:

1. ELFORCE - requests the forces in a set of structural elements or the temperature gradients and fluxes in a set of structural or heat elements in heat transfer.
2. STRESS - requests the stresses in a set of structural elements or the velocity components in a fluid element in acoustic cavity analysis.
3. SPCFORCES - requests the single-point forces of constraint at a set of points or the thermal power transmitted at a selected set of points in heat transfer.
4. BLOAD - selects a set of applied loads for output.
5. ACCELERATION - requests the accelerations for a selected set of PHYSICAL points (grid, scalar and fluid points plus extra points introduced for dynamic analysis).
6. DISPLACEMENT - requests the displacements for a selected set of PHYSICAL points or the temperatures for a selected set of PHYSICAL points in heat transfer or the pressures for a selected set of PHYSICAL points in hydroelasticity.
7. VELCITY - requests the velocities for a selected set of PHYSICAL points or the change in temperatures with respect to time for a selected set of PHYSICAL points in heat transfer.
8. HARMONICS - controls the number of harmonics that will be output for requests associated with the conical shell, axisymmetric solids and hydroelastic problems.
9. ESE - requests structural element strain energies in Rigid Format 1.
10. GPFORCE - requests grid point force balance due to element forces, forces of single point constraint, and applied loads in Rigid Format 1.
11. THERMAL - requests temperatures for a set of PHYSICAL points in heat transfer.
12. PRESSURE - requests pressures for a set of PHYSICAL points in hydroelasticity.
13. CSP - selects contact surface points to be output

2.3.3 Subcase Definition

In general, a separate subcase is defined for each loading condition. In statics problems separate subcases are also defined for each set of constraints. In complex eigenvalue analysis

CASE CONTROL DECK

Case Control Data Card CSP - Contact Surface Point Selection

Description: Selects the interface contact surface points for a static aeroelastic analysis.

Format and Examples:

CSP = n

CSP = 31

<u>Option:</u>	<u>Meaning</u>
n	Set identification number of a CSP card (integer > 0).

Remarks:

1. The normal displacement difference will be output for the selected interface contact surface points.
2. This card should select only those points of the interface contact surfaces where "contact" constraint conditions were not invoked. Use the GPFORCE Case Control Card to select points for which "contact" constraint conditions were invoked.

BULK DATA DECK

Input Data Card CSP Contact Surface Points

Description: Defines interface contact surface points for use in static aeroelastic problems.

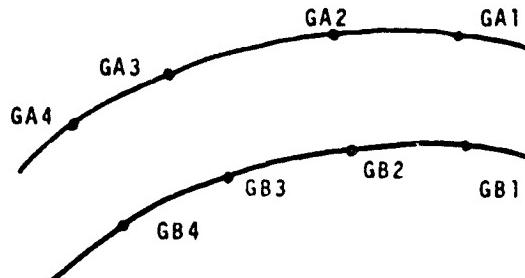
Format and Example:

1	2	3	4	5	6	7	8	9	10
CSP	SID	GA1	GB1	GA2	GB2	GA3	GB3		+ABC
CSP	13	5	9	10	12	13	23		+CSP1
+ABC	GA4	GB4	GA5	GB5	-etc-				
+CSP1									

<u>Field</u>	<u>Contents</u>
SID	Identification number of contact surface set (integer > 0).
GA1, GB1	Grid point identification numbers of node point pairs at interface contact locations (integer > 0).

Remarks:

1. Contact surface sets must be selected in the Case Control Deck (CSP = SID) to be used by NASTRAN
2. The normal displacement difference between each GA1 and GB1 pair will be output if this SID is selected.
3. Only those points where "contact" constraints were not invoked should be selected here. Contact surface points where "contact" constraints were invoked should be selected by a GPFORCE data card to output element forces at the contact locations.



Interface contact surfaces represented by node pairs (GA1, GB1), (GA2, GB2), (GA3, GB3) and (GA4, GB4)

BULK DATA DECK

Input Data Card

FLFACT

Aerodynamic Physical Data

Description: Used to specify densities, Mach numbers or interblade phase angles, and reduced frequencies for flutter analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FLFACT	SID	F1	F2	F3	F4	F5	F6	F7	ABC
FLFACT	97	.3	.7	3.5					
+BC	F	F9	-etc-						

Field

Contents

SID Set identification number (unique integer > 0).

F1 Aerodynamic factor (real).

Remarks:

1. These factors must be selected by a FLUTTER data card to be used by NASTRAN.
2. Imbedded blank fields are forbidden.
3. Parameters must be listed in the order in which they are to be used within the looping of flutter analysis.

BULK DATA DECK

Input Data Card

FLUTTER

Aerodynamic Flutter Data

Description: Defines data needed to perform flutter analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHOD	DENS	MACH	RFREQ	IMETH	NVALUE		
FLUTTER	19	K	119	219	319	S	5		

Field

SID Set identification number (unique integer > 0).

METHOD Flutter analysis method, "K" for k-method (BCD).

DENS Identification number of an FLFACt data card specifying density ratios to be used in flutter analysis (integer ≥ 0).

MACH Identification number of an FLFACt data card specifying MACH numbers or interblade phase angles (m) to be used in flutter analysis (integer ≥ 0).

RFREQ Identification number of an FLFACt data card specifying reduced frequencies (k) to be used in flutter analysis (integer ≥ 0).

IMETH Choice of interpolation method for matrix interpolation (BCD: L - linear, S = surface, default is S).

NVALUE Number of eigenvalues for output and plots (integer > 0).

Remarks:

1. The FLUTTER data card must be selected in Case Control Deck (FMETHOD - SID).
2. The density is given by $\rho \cdot RH\theta REF$ where ρ is the density ratio given on the FLFACt data card and $RH\theta REF$ is the reference density given on the AERO data card.
3. The reduced frequency is given by $k = (REFC \cdot \omega / 2 \cdot V)$, where $REFC$ is given on the AERO data card, ω is the circular frequency and V is the velocity.

BULK DATA DECK

Input Data Card MKAERØ1

Mach Number - Frequency Table

Description: Provides a table of Mach numbers or interblade phase angles (m) and reduced frequencies (k) for aerodynamic matrix calculation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MKAERØ1	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	ABC
MKAERØ1	.1	.7							+ABC
+BC	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	
+BC	.3	.6	1.0						

Field

Contents

m_i List of Mach numbers or interblade phase angles (Real, $1 \leq i \leq 8$).

k_j List of reduced frequencies (Real, $1 \leq j \leq 8$).

Remarks:

1. Blank fields end the list, and thus cannot be used for 0.0.
2. Combinations of (m, k) will be used.
3. The continuation card is required.
4. Mach numbers are input for wing flutter and interblade phase angles for blade flutter.

BULK DATA DECK

Input Data Card MKAERØ2 Mach Number - Frequency Table

Description: Provides a list of Mach numbers or interblade phase angles (m) and reduced frequencies (k) for aerodynamic matrix calculation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MKAERØ2	m_1	k_1	m_2	k_2	m_3	k_3	m_4	k_4	
MKAERØ2	.10	.30	.10	.60	.70	.30	.70	1.0	

Field

Contents

m_1, k_1

List of pairs of Mach numbers or interblade phase angles (Real) and reduced frequencies (Real) (imbedded blank pairs are skipped).

Remarks:

1. This card will cause the aerodynamic matrices to be computed for a set of parameter pairs.
2. Several MKAERØ2 cards may be in the deck.
3. Mach numbers are input for wing flutter and interblade phase angle for blade flutter.

NASTRAN DATA DECK

PARAM (Cont.)

- y. KMAX - optional in static analysis with cyclic symmetry (rigid format T4). The integer value of this parameter specifies the maximum value of the harmonic index. The default value is ALL which is NSEGS/2 for NSEGS even and (NSEGS-1)/2 for NSEGS odd.
- z. KINDEX - required in normal modes with cyclic symmetry (rigid format T5). The integer value of this parameter specifies a single value of the harmonic index.
- aa. NODJE - optional in modal flutter analysis. A positive integer of this parameter indicates user supplied downwash matrices due to extra points are to be read from tape via the INPUTT2 module in the rigid format. The default value is -1.
- ab. P1, P2 and P3 - required in modal flutter analysis when using NODJE parameter. See Section 5.3.2 for tape operation parameters required by INPUTT2 module. The defaults for P1, P2 and P3 are -1, 11 and TAPEID, respectively.
- ac. VREF - optional in modal flutter analysis. Velocities are divided by the real value of this parameter to convert units or to compute flutter indices. The default value is 1.0.
- ad. PRINT - optional in modal flutter analysis. The BCD value, ND, of this parameter will suppress the automatic printing of the flutter summary for the k method. The flutter summary table will be printed if the BCD value is YES for wing flutter, or YESB for blade flutter. The default is YES.
- ae. APRESS - optional in static aeroelastic analysis. A positive integer value will generate aerodynamic pressures. A negative value (the default) will suppress the generation of aerodynamic pressure loads.
- af. ATEMP - optional in static aeroelastic analysis. A positive integer value will generate aerodynamic temperature loads. A negative value (the default) will suppress the generation of aerodynamic thermal loads.
- ag. STREAML - optional in static aeroelastic analysis. STREAML=1 causes the punching of STREAML1 bulk data cards. STREAML=2 causes the punching of STREAML2 bulk data cards. STREAML=3 causes both STREAML1 and STREAML2 cards to be punched. The default value, -1, suppresses punching of any cards.
- at. PGEOM - optional in static aeroelastic analysis. PGEOM = 1 causes the punching of GRID bulk data cards. PGEOM = 2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEOM = 3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default, -1, suppresses punching of any cards.
- ai. IPRT - optional in static aeroelastic analysis. If IPRT > 0, then intermediate print will be generated in the ALG module based on the print option in the ALGDB data table. If IPRT = 0 (the default), no intermediate print will be generated.

NASTRAN DATA DECK

PARAM (Cont.)

- ej. SIGN - optional in static aerothermoelastic analysis. Controls the type of analysis being performed. SIGN = 1.0 for a standard analysis SIGN = -1.0 for a design analysis. The default is 1.0.
- ak. ZORIGN, FXC00R, FYC00R, FZC00R - optional in static aerothermoelastic analysis. These are modification factors. The defaults are ZORIGN = 0.0, FXC00R = 1.0, FYC00R = 1.0, and FZC00R = 1.0.
- el. MINMACH - optional in blade flutter analysis. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid. The default is 1.0.
- am. MAXMACH - optional in blade flutter analysis. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid. The default value is 0.80.
- an. IREF - optional in blade flutter analysis. This defines the reference streamline number. IREF must be equal to a SLN on a STREAML2 bulk data card. The default value, -1, represents the streamline at the blade tip. If IREF does not correspond to a SLN, then the default will be taken.
- ao. MTYPE - optional in cyclic modal blade flutter analysis. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = COSINE for cosine components. The default BCD value is COSINE.
- ap. KTOUT - optional in static aerothermoelastic analysis. A positive integer of this parameter indicates that the user wants to save the total stiffness matrix on tape (GIN0 file INPT) via the OUTPUT1 module in the rigid format. The default is -1.
- aq. KGGIN - optional in compressor blade cyclic modal flutter analysis. A positive integer of this parameter indicates that the user supplied stiffness matrix is to be read from tape (GIN0 file INPT) via the INPUT1 module in the rigid format. The default is -1.

BULK DATA DECK

Input Data Card

STREAML1

Blade Streamline Data

Description: Defines grid points on the blade streamline from blade leading edge to blade trailing edge.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML1	SLN	G1	G2	G3	G4	G5	G6	G7	+ABC
STREAML1	3	2	4	6	8	10			
+ABC	G8	G9	-etc-						
+ABC									

Alternate Form:

STREAML1	SLN	GID1	"THRU"	GID2	X	X	X	X	X
STREAML1	5	6	THRU	12					

Field

Contents

SLN Streamline number (integer > 0).

G1, GID1 Grid point identification numbers (integer > 0).

Remarks:

1. This card is required for blade steady aeroelastic and blade flutter problems.
2. There must be one STREAML1 card for each streamline on the blade. For blade flutter problems, there must be an equal number of STREAML1 and STREAML2 cards.
3. The streamline numbers, SLN, must increase with increasing radial distance of the blade section from the axis of rotation. The lowest and the highest SLN, respectively, will be assumed to represent the blade sections closest to and farthest from the axis of rotation.
4. All grid points should be unique.
5. All grid points referenced by GID1 through GID2 must exist.
6. Each STREAML1 card must have the same number of grid points. The nodes must be input from the blade leading edge to the blade trailing edge in the correct positional order.

C.R

BULK DATA DECK

Input Data Card

STREAML2

Blade Streamline Data

Description: Define aerodynamic data for a blade streamline.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML2	S_N	NSTNS	STAGGER	CHORD	RADIUS	BSPACE	MACH	DEN	+abc
STREAML2	2	3	23.5	1.85	6.07	.886	.934	.066	

+abc	VEL	FLOWA							
+ABC	1014.2	55.12							

Field

Contents

SLN	Streamline number (Integer >0)
NSTNS	Number of computing stations on the blade streamline. $(3 \leq \text{NSTNS} \leq 10, \text{ Integer})$
STAGGER	Blade stagger angle (-90.0 < stagger < 90.0, degrees)
CHORD	Blade chord (real >0.0)
RADIUS	Radius of streamline (real >0.0)
BSPACE	Blade spacing (real >0.0)
MACH	Relative flow mach number at blade leading edge (real >0.0)
DEN	Gas density at blade leading edge (real >0.0)
VEL	Relative flow velocity at blade leading edge (real >0.0)
FLOWA	Relative flow angle at blade leading edge (-90.0 < FLOWA < 90.0, degrees)

Remarks:

1. At least three (3) and no more than ten (10) STREAML2 cards are required for a blade flutter analysis.
2. The streamline number, SLN, must be the same as its corresponding SLN on a STREAML1 card. There must be a STREAML1 card for each STREAML2 card.
3. It is not required that all streamlines be used to define the aerodynamic matrices used on blade flutter.

RIGID FORMATS

The following rigid formats for structural analysis are currently included in NASTRAN:

1. Static Analysis
2. Static Analysis with Inertia Relief
3. Normal Mode Analysis
4. Static Analysis with Differential Stiffness
5. Buckling Analysis
6. Piecewise Linear Analysis
7. Direct Complex Eigenvalue Analysis
8. Direct Frequency and Random Response
9. Direct Transient Response
10. Modal Complex Eigenvalue Analysis
11. Modal Frequency and Random Response
12. Modal Transient Response
13. Normal Modes Analysis with Differential Stiffness
14. Static Analysis with Cyclic Symmetry
15. Normal Modes Analysis with Cyclic Symmetry
16. Static Aerothermoelastic Analysis with Differential Stiffness

The following rigid formats for heat transfer analysis are included in NASTRAN:

1. Linear Static Heat Transfer Analysis
3. Nonlinear Static Heat Transfer Analysis
9. Transient Heat Transfer Analysis

The following rigid formats for aeroelastic analysis are included in NASTRAN:

9. Compressor Blade Cyclic Modal Flutter Analysis (Subsonic and Supersonic)
10. Modal Flutter Analysis (Subsonic)

3.1.1 Input File Processor

The Input File Processor operates in the Preface prior to the execution of the DMAP operations in the rigid format. A complete description of the operations in the Preface is given in the Programmer's Manual. The main interest here is to

indicate the source of data blocks that are created in the Preface and hence appear only as inputs in the DMAP sequences of the rigid formats. None of the data blocks created by the Input File Processor are checkpointed, as they are always regenerated on restart. The Input File Processor is divided into five parts. The first part (IFP1) processes the Case Control Deck, the second part (IFP) processes the Bulk Data

COMPRESSOR BLADE MESH GENERATOR

3.21 COMPRESSOR BLADE MESH GENERATOR

3.21.1 DMAP Sequence for Compressor Blade Mesh Generator

RIGID FORMAT DMAP LISTING

SERIES 0

DMAP APPROACH, COMPRESSOR BLADE MESH GENERATOR

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GO ERR=2 NOLIST NODECK NOREF NOOSCAR

1 BEGIN \$

2 ALG CASECC,,,ALGDB,, / CASECCA,GEOM3A / C,N,-1 / C,N,-1 /
V,Y,STREAML=1 / V,Y,PGEOM=2 / V,Y,IPRT=1 \$

3 END \$

RIGID FORMATS

3.21.2 Description of DMAP Operations for Compressor Blade Mesh Generator

2. ALG generates GRID, CTRIA2, PTRIA2 and STREAM1 bulk data cards. These cards are output via the system card punch. The GRID and CTRIA2 cards represent a compressor blade mesh. The aerodynamic input data is checked by performing an aerodynamic analysis.

COMPRESSOR BLADE MESH GENERATOR

3.21.3 Output for the Compressor Blade Mesh Generator

The GRID, CTRIA2, PTRIA2 and STREAML1 bulk data cards are punched.

Aerodynamic output is printed.

3.21.4 Case Control Deck, DTI Table and Parameters for the Compressor Blade Mesh Generator

1. Only TITLE, SUBTITLE and LABEL cards are processed, all other case control cards are ignored.
2. The only required input is the ALGDB data table. This data block is input via Direct Table Input (DTI) bulk data cards. ALGDB contains all the aerodynamic input necessary for the ALG module. For a detailed description of the ALGDB data block input see Section 1.15.3.1 of the User's Manual.

The following user parameters are used by the Compressor Blade Mesh Generator.

1. STREAML - Optional - A value of 1 causes the punching of STREAML1 bulk data cards. A value of 2 causes the punching of STREAML2 bulk data cards. A value of 3 causes the punching of both STREAML1 and STREAML2 cards. The default value, -1, suppresses the punching of all cards.
2. PGEOM - Optional - A value of 1 causes the punching of GRID bulk data cards. A value of 2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEOM = 3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default value, -1, suppresses the punching of all cards.
3. IPRT - Optional - a non-negative value of this parameter will allow intermediate print to be generated by the ALG module based on the print option in the ALGDB data table. The default value, 0, suppresses all intermediate print.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

3.22 Static Aerothermoelastic Analysis with Differential Stiffness

3.22.1 DMAP Sequence for Static Aerothermoelastic Analysis with Differential Stiffness.

RIGID FORMAT DMAP LISTING
SERIES J

DISPLACEMENT APPROXACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GO ERR=2 NOLIST NOECK NOREF NOUSCAR

1 BEGIN NU.16 STATIC AEROTHERMOELASTIC WITH DIFFERENTIAL STIFFNESS \$

2 **(GP1)** GEOM1,GEUM2,/GPL,EQEXIN,GPOT,CSTM,BGPOT,SIL/V,N,LUSET/ V,N,
NUGPDT \$

3 SAVE LUSET,NUGPDT \$

4 **(COND)** ERRURI,NUGPDT \$

5 CHKPNT GPL,EQEXIN,GPDT,CSTM,BGPOT,SIL \$

6 **(GP2)** GFOM2,EQEXIN/ECT \$

7 CHKPNT ECT \$

8 PARAML PCOB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NOPCOB \$

9 **(PARAM)** // C,N,COMPLEX // V,Y,SIGN / C,N,O.O / V,N,CSIGN \$

10 PURGE PLTSETX,PLTPAR,GPSETS,ELSETS/NOPCOB \$

11 **(COND)** PI,NOPCOB \$

12 **(PLTSET)** PCOB,EQEXIN,LCT/PLTSETX,PLTPAR,GPSETS,ELSETS/V,N,NSIL/ V,N,
JUMPPLUT=-1 \$

13 SAVE NSIL,JUMPPLUT \$

14 **(PRT4SG)** PLTSETX// \$

15 PARAM //C,N,4PY/Y,V,PLTFLG/C,N,I/C,N,I \$

16 PARAM //C,N,MPY/V,N,PFIL/C,N,O/C,N,O \$

17 **(COND)** PI,JUMPPLUT \$

18 **(PLOT)** PLTPAR,GPSETS,ELSETS,CASECC,BGPOT,EQEXIN,SIL,,,/PLUTX1/ V,N,
NSIL/V,N,LUSET/V,N,JUMPPLUT/V,N,PLTFLG/V,N,PFIL \$

19 SAVE JUMPPLUT,PLTFLG,PFIL \$

20 **(PRT4SG)** PLUTX1// \$

21 LABEL PI \$

22 CHKPNT PLTPAR,GPSETS,ELSETS \$

RIGID FORMATS

RIGID FORMAT DMAP LISTING SERIES 0

DISPLACEMENT APPROXACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

1

```
23 GP3 GEOM3,EQEXIN,GEOM2/SLT,JPPT/V,N,NUGRAV $  
24 SAVE NUGRAV $  
25 PARAM //C,N,ANU/V,N,NOMGG/V,N,NUGRAV/V,Y,GROPNT=-1 $  
26 CHKPNT SLT,JPPT $  
27 TAI ECT,EP1,BGPDT,SIL,JPPT,CSTM/EST,GEI,GPECT,/V,N,LUSET// V,N,  
NUSIMP/C,N,1/V,N,NUGENL/V,N,GENEL $  
28 SAVE NOSIMP,NUGENL,GENEL $  
29 CUND ERROR1,NUSIMP $  
30 PURGE UGPST/GENEL $  
31 CHKPNT EST,GPECT,GFI,OGPST $  
32 PARAM //C,N,ADD/V,N,NOKGGX/C,N,L/C,N,O $  
33 EMG EST,CSTM,MPT,DIT,GEOM2,/KELM,KUIT,C,ELM,MDICT,,/V,N,NOKGGX// V,  
N,NOMGG/C,N,/C,N,/C,N,C,Y,COUPMASS/C,Y,CPBAR/C,Y,CPRCD/C,Y,  
CPQUADI/C,Y,CPQUAD2/C,Y,CPTRIAI/C,Y,CPTRIAZ/C,Y,CPTUBE/C,Y,  
CPUDPLT/C,Y,CPTRPLT/C,Y,CPTRBSC $  
34 SAVE NOKGGX,NOMGG $  
35 CHKPNT KELM,KUIT,C,ELM,MDICT $  
36 CUND JMPKUG,NOKGGX $  
37 EMA GPECT,KUIT,C,ELM/KUGX,GPST $  
38 CHKPNT KUGX,GPST $  
39 LABEL JMPKUG $  
40 CUND JMPNCG,NUMGG $  
41 EMA GPFCT,MDICT,C,ELM/MGG,/L,N,-1/C,Y,WTHMASS=1.0 $  
42 CHKPNT MGG $  
43 LABEL JMPNCG $  
44 CUND LBL1,GRUPNT $  
45 CUND ERROR4,NOMGG $
```

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LISTING
SERIES U

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

46 **GPGC** BGPDT,CSTM,EDEXIN,MUG/U,PWG/V,+,GRUPNT/C,Y,WTHMASS 8
47 **DPP** DGPNG++++// 8
48 LABEL LBL 1 8
49 **EQUIV** KGGX,KGG/NUGENL 8
50 CHKPNT KGG 8
51 **CUND** LBL 11,NUGENL 8
52 **SMA3** GEI,KGGX/KGG/V,N,LUSET/V,N,NUGENL/V,N,NOSIMP 8
53 CHKPNT KGG 8
54 LABEL LBL 12 8
55 PARAM //L,N,MPY/V,N,NSKIP/C,N,O/C,N,O 8
56 **GP4** CAECC,GEUMG,EDEXIN,SIL,JPDT,BGPDT,CSTM/RG,YS,USET,ASET/V,N,
LUSET/V,N,MPCF1/V,N,MPCF2/V,N,SINGLE/V,N,OMIT/V,N,REACT/V,N,
NSkip/V,N,REPEAT/V,N,NUSET/V,N,NOL/V,N,NUA/C,Y,SUB10 8
57 SAVE MPCF1,MPCF2,SINGLE,UMIT,REACT,NSkip,REPEAT,NOSEI,NOL,NOA 8
58 **CUND** ERKOR5,NUL 8
59 PURGE GM/MPCF1/GU,KOU,LOU,PO,UUOV,RUOV/OMIT/PS,KFS,KSS,QG/SINGLE/
UBUOV/OMIT/YBS,PBS,KBFS,KBSS,KUFS,KUSS/SINGLE 8
60 CHKPNT GM,RG,GO,KOU,LOU,PO,UUOV,RUOV,YS,PS,KFS,KSS,USET,ASET, UUOOV,
YBS,PBS,KBFS,KBSS,KUFS,KDSS,QG 8
61 **CUND** LBL 4D,REACT 8
62 JUMP ERKOR2 8
63 LABEL LBL 4D 8
64 **CUND** LBL 4,GENELS
65 **GPSP** GPL,JPST,USET,SIL/OGPST/V,N,NOGPST 8
66 SAVE NOGPST 8
67 **CUND** LBL 4,NUGPST 8
68 **DPP** UGPST++++// 8

RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

69	LABEL	LBL4 \$
70	EQUIV	KGG,KNY/MPCFL \$
71	CHKPNT	KNN \$
72	COND	LHL2,MPCF2 \$
73	MCE1	USET,KG/GM \$
74	CHKPNT	GM \$
75	MCE2	USET,GM,KGG,,,/KNN,,, \$
76	CHKPNT	KNY \$
77	LABEL	LBL2 \$
78	EQUIV	KNN,KFF/SINGLE \$
79	CHKPNT	KFF \$
80	COND	LBL3,SINGLE \$
81	SCE1	USET,KNN,,,/KFF,KFS,KSS,,, \$
82	CHKPNT	KFS,KSS,KFF \$
83	LABEL	LBL3 \$
84	EQUIV	KFF,KAA/OMIT \$
85	CHKPNT	KAA \$
86	COND	LBL5,OMIT \$
87	SMP1	USET,KFF,,,/GO,KAA,KOO,LOO,,,,, \$
88	CHKPNT	GO,KAA,KOO,LOO \$
89	LABEL	LBL5 \$
90	ROMG2	KAA/LLL \$
91	CHKPNT	LLL \$
92	SSGL	SLT,BGPOT,CSTM,SIL,EST,MPT,GPTT,EDT,MGG,CASECC,DIT/PGNA / V,N, LUSET/C,N,I \$
93	CHKPNT	PGNA \$

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT DMAP LISTING
SET-ES 0

DISPLACEMENT APPROXACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
94 PARAM //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP $  
95 (CONU) NUAL,ALUAD $  
96 (CALC) CASECC,,EQEXIN,,ALGDU,, / CASECCAL,GEOM3AL / S,Y,APRESS/S,Y,  
ATEMP/C,N,-1/C,N,-1/V,Y,IPRTCL/S,N,IFAIL $  
97 COND FINIS,IFAIL $  
98 PARAM //C,N,AND /V,N,ALUAD /V,Y,APRESS /V,Y,ATEMP $  
99 COND NUAL,ALUAD $  
100 GP3 GEUM3AL,EQEXIN,GEOM2 / SLTAL,GPTTAL / V,N,NOGRAV $  
101 CHKPNT SLTAL,GPTTAL $  
102 (SSCI) SI.TA1,UGPDT,: STM,SIL,EST,MPT,GPTTAL,EUT,MGG,CASECCAL,DIT /  
PGAI / V,N,LUSET / C,N,I $  
103 CHKPNT PGAI $  
104 (ACC) PGVA,PGAI / PG $  
105 LABEL NUAL $  
106 (EQUIV) PGVA,PG/ALOAD $  
107 CHKPNT PG $  
108 (EQUIV) PG,PL/LUSET $  
109 CHKPNT PL $  
110 (COND) LBL10,NOSET $  
111 (SSG2) USET,GN,YS,KFS,GO,,PG/,PU,PS,PL $  
112 CHKPNT PU,PS,PL $  
113 LABEL LBL10 $  
114 (SSG3) LLL,KAA,PL,LOU,KOO,PO/ULV,UUV,RULV,RUV/V,N,OMIT/V,Y,IRES=-1/  
C,N,I/V,N,EPST $  
115 SAVE EPSI $  
116 CHKPNT ULV,UUV,RULV,RUV $  
117 (COND) LBL9,IKES $
```

RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

118 **(MATGPK)** GPL,USET,SIL,RULV//C,N,L \$
119 **(MATGPM)** GPL,USET,SIL,RUUV//C,N,U \$
120 LABEL LBL9 \$
121 **(SCH1)** USET,,ULV,UOJV,YS,GO,GM,PS,KFS,KSS,/UGV,PG1,QG/C,N,I/C,N,DSO \$
122 CHKPNT UGV,QG \$
123 **(SDR2)** CASECC,CSTM,MPT,DIT,EQEIN,SIL,GPTT,EDT,BGPDT,,QG,UGV,EST,,PG/
OPG1,OUG1,OUGV1,UESI,DEF1,PUGV1/C,N,DSO \$
124 PARAM //C,N,MPY/V,N,CARDNO/C,N,O/C,N,O \$
125 **(DFP)** OUGV1,OPG1,OUG1,UEFL,UESI,//V,N,CARDNO \$
126 SAVE CARDNO \$
127 **(COND)** P2,JUMPPLOT \$
128 **(PLOT)** PLTPAR,GPSETS,ELSE IS,CASECC,BGPDT,EQEIN,SIL,PUGV1,,GPECT,UESI/
PLUTX2/V,N,NSIL/V,N,LSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFILE \$
129 SAVE PFILE \$
130 **(PRMSG)** PLUTX2// \$
131 LABEL P2 \$
132 **(TAI)** ECT,EPT,BGPDT,SIL,GPTT,CSTM/X1,X2,ECPT,GPCT/V,N,LSET/ V,N,
NUSIMP/C,N,O/V,N,NUENL/V,N,GENEL \$
133 **(DSMG1)** CASECC,GPTT,SIL,EDT,UGV,CSTM,MPT,ECPT,GPCT,DIT/KDGG/ V,N,
DSCOSETS
134 CHKPNT KDGG \$
135 **(COND)** NUALO,ALOAD \$
136 **(EQUIV)** PGNA,PG \$
137 LABEL NUALO \$
138 PARAM //C,N,ADD/V,N,SHIFT/C,N,-1/C,N,O \$
139 PARAM //C,N,ADD/V,N,COUNT/V,N,ALWAYS=-1/V,N,NEVER= 1 \$
140 PARAMK //C,N,ADD/V,N,USEPSI/C,N,O,O/C,N,O,O \$

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

```
141 PARAML Y$/C,N,NULL/C,N,/C,N,/C,N,/V,N,NOYS $  
142 JUMP UUTLP TOP $  
143 LABEL UUTLP TUP >  
144 EQUIV PG,PG1/NUYS $  
145 CHKPNT PG1 $  
146 PARAM //C,N,KLUCK,V,N,TO $  
147 EQUIV KDGG,KDNN/MP,F2 $  
148 CHKPNT KDNN $  
149 COND LBL2D,MPCF2 $  
150 MCE2 USET,GM,KDGG,,,/KDNN,,, $  
151 CHKPNT KDNN $  
152 LABEL LBL2D $  
153 EQUIV KUNN,KUFF/SINGLE $  
154 CHKPNT KDF $  
155 COND LBL3D,SINGLE $  
156 SCE1 USET,KDNN,,,/KDF,KDF,S,KDSS,,, $  
157 CHKPNT KUFF,KUFS,KDSS $  
158 LABEL LBL3D $  
159 EQUIV KUFF,KDAA/OMIT $  
160 CHKPNT KCAA $  
161 COND LBL5D,OMIT $  
162 SMP2 USET,GO,KUFF/KDAA $  
163 CHKPNT KDAE ?  
164 LABEL LBL5D $  
165 ADD KAA,KDAA / KBL / C,N,(1.0,0.0) / V,N,CSIGN $
```

RIGID FORMATS

RIGID FORMAT DMAP LISTING

SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

166	ADD	KFS,KDFS/ KUFS / C,N,(1.0,0.0) / V,N,CSIGN \$
167	ADN	KSS,KUSS/ KASS / C,N,(1.0,0.0) / V,N,CSIGN \$
168	AND	PGOK,NOVS \$
169	APYAD	KASS,YS,/PSS/C,N,0/C,N,1/C,N,1/C,N,1 \$
170	MPYAD	KDFS,YS,/PFS/C,N,0/C,N,1/C,N,1/C,N,1 \$
171	UMERGE	USFT,PFS,PSS/PN/C,N,N/C,N,F/C,N,S \$
172	EQUIV	PN,PGX/4PCF2 \$
173	COND	LBLEQ,4PCF2 \$
174	UMERGE	USFT,PN,/PGX/C,N,0/C,N,N/C,N,M \$
175	LABEL	LBL50 \$
176	ADD	PG4,PG/PGG/C,N,(-1.0,0.0) \$
177	EQUIV	PG3,PG1/ALWAYS \$
178	LABEL	PGOK \$
179	ADD	PG1,/PG3/ \$
180	COPY	UGV / AUGV \$
181	FBMG2	KBLI/LBLI/V,N,POWER/V,N,DET \$
182	SAVE	DET,PCWER \$
183	CHKPNT	LBLI \$
184	OPTPAF	//C,N,C/C,N,DET \$
185	OPTPAFM	//C,N,0/C,N,PCWER \$
186	JUMP	INLPTRP \$
187	LABEL	INLPTRP \$
188	PAFA4	//C,N,KLOCK/V,N,TI \$
189	COND	NOALL,ALCAD \$
190	ALG	CASFCC,EDT,EQE X/V,AUGV,ALGCC,CSTM,RGPDT / CASFCCA,CFOM3A /S,Y, APRESS/S,Y,ATFMP/C,N,-1/C,N,-1/V,Y,IPRTCL/S,N,IFAIL/V,Y,SIGN/V,

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LISTING
SERIES 3

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

Y,ZDIGN/V,Y,FXCOR/V,Y,FYCOOR/V,Y,FZCOOR \$
191 CUND DUNE,IFAIL \$
192 PARAM //C,N,MPY /V,Y,IPRTCL /C,N,O \$
193 PARAM //C,N,AND /V,N,ALOAD /V,Y,APRESS /V,Y,ATEMP \$
194 COND NUAL1,ALOAD \$
195 GP3 GEOM3A,EQEXIN,GEUM2/SLTA,GPTTA/V,N,NUASL/V,N,NUGRAV/V,N,NOATL \$
196 SSG1 SLTA,BGPUT,CSTM,SIL,EST,MPT,GPTTA,EDT,MGG,CASECCA,DIT /PGA /V,
N,LUSET /C,N,IS
197 ADD PG1,PGA / PG2 \$
198 LABEL NUAL1 \$
199 EQUIV PG1,PG2 / ALLOAD \$
200 CHKPNT PG2 \$
201 SSG2 USET,GM,YS,KDFS,GU,,PG2 /,PBO,PBS,PBL \$
202 SSG3 LBLL,KBLL,PBL,,,/LULV,,RUBLV,/C,N,-1/V,Y,IRES/V,N,NOSKIP/V,N,
EPSI \$
203 SAVE EPSI \$
204 CHKPNT UBLV,RUBLV \$
205 CUND LBL9J,IRES \$
206 MATGRU GPL,LSET,SIL,RUBLV//C,N,L \$
207 LABEL LBL9J \$
208 SDRI USET,,CHLV,,YS,GO,GM,PBS,KBFS,KBSS,/UBGV,,QBG/C,N,1/C,N,DS1 \$
209 CHKPNT UBGV,QBG \$
210 COND NUAL2,ALOAD \$
211 EQUIV UBGV,AUGV \$
212 LABEL NUAL2 \$
213 ADD UBTJ,UGV/DUGV/C,N,(-1.0,0.0) \$

RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 0

DISPLACEMENT APPROACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

214	(DSMG1)	CASECC,GPTT,SIL,EDT,UUGV,CSTM,MPT,ECPT,GPCT,DIT/DKDGGS/V,N, DSCOSET \$
215	CHKPNT	DKDGGS \$
216	(CPYAD)	DKUGG,UUGV,PGO/PGII/C,N,0/C,N,L/C,N,I/C,N,L \$
217	(ADD)	PGII,PGA / PG12 \$
218	(DSCIK)	PG2,PG12,UBGV /C,Y,EPSIO=1.E-5 /V,N,DSEPSI / C,Y,NT=10 /V,N, TU /V,N,TI /V,N,DONE /V,N,SHIFT /V,N,COUNT/C,Y,BETAD=4 \$
219	SAVE	DSEPSI,JDONE,SHIFT,COUNT \$
220	(COND)	DONE,DONE \$
221	(COND)	SHIFT,SHIFT \$
222	(EQUIV)	PL,PG1/NEVER \$
223	(EQUIV)	PGII,PG1/ALWAYS \$
224	(EQUIV)	PG1,PGII/NEVER \$
225	(REPT)	INLPTUP,1000 \$
226	(TABPT)	PGII,PG1,PG,,// \$
227	LABEL	SHIFT \$
228	(ADD)	DKDGGS,KDGGS/KDGGS1/C,N,(-1.0,0.0) \$
229	CHKPNT	KDGGS1 \$
230	(EQUIV)	UBGV,UUV/ALWAYS/KDGGS1,KDGGS/ALWAYS \$
231	CHKPNT	KDGGS \$
232	(EQUIV)	KDGGS,KDGGS1/NEVER/LGV,UUGV/UUGV/NEVER \$
233	(REPT)	OUTLPTUP,1000 \$
234	(TABPT)	KDGGS1,KDGGS,UUV,,// \$
235	LABEL	DOVE \$
236	PARAM	//C,N,NOP / V,Y,KTOUT=-1 \$
237	(COND)	JMPKTOUT,KTOUT \$

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

RIGID FORMAT UMAP LIS. ING
SERIES D

DISPLACEMENT APPROXACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

238 **ADC** KG0,KG0G / KTOTAL / C,N,(1.0,0.0) / V,N,CSIGN \$
239 **QUTPUT** KTOTAL,,, // C,Y,LOCATION=-1 / C,Y,INPTUNIT=0 \$
240 **QUTPUT** ..., // C,N,-3 / C,N,0 \$
241 LABEL JMPKTOUT \$
242 CHKPNT CSTM \$
243 **ALG** CASECC,EDT,EQEXIN,LBGV,ALGDB,CSTM,BGPDT / CASECCB,GEU4JB / C,N,
-1/C,N,-1/V,Y,STREAML/V,Y,PGEOM/V,Y,IPRTCF/S,N,IFAIL/V,Y,SIGN/
V,Y,ZORIGN/V,Y,FACOUR/V,Y,FYCOOR/V,Y,FZCOOR \$
244 **SUN2** CASECC,CSTM,MPT,DIRT,EQEXIN,SIL,GPTT,EDT,BGPDT,,QBG,UBGV,EST,,/
QUBG1,QUBGV1,DESB1,DEFB1,PUBGV1/C,N,DS1 \$
245 **DFP** QUBGV1,DEFB1,DESB1,,,//V,N,CARDNU \$
246 SAVE CAKDNU \$
247 **SDK1** USET,PG2,UBLV,,YS,GO,GM,PBS,KBF5,KBSS, / AUBGV,APGG,AQBG / C,N,
1 /C,N,DS1 \$
248 **GPFDR** CASECC,AUBGV,KELM,KDICT,ECT,EQEXIN,GPECT,APGG,AQBG / UNRGY1,
OGPFU1 / C,N,STATICS \$
249 **DFP** UNRGY1,OGPFU1,,, // \$
250 **CUND** P3,JUMPPLOT \$
251 **PLUT** PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,PUBGV1,,GPECT,
DESB1/PLUTX3/V,N,NSIL/V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,
PFILE \$
252 SAVE PFILE \$
253 **PRTMSG** PLUTX3// \$
254 LABEL P3 \$
255 **JUMP** FINIS \$
256 LABEL ERROR1 \$
257 **PRTPAKM** //C,N,-1/C,N,DIFFSTIF \$
258 LABEL ERROR2 \$
259 **PRTPAKM** //C,N,-2/C,N,DIFFSTIF \$

RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES 3

DISPLACEMENT APPROXACH, RIGID FORMAT 16

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
260 LABEL ERKOR4 $  
261 PNTPARM //C,N,-4/C,N,DIFFSTIF $  
262 LABEL ERKOR5 $  
263 PRTPARM //C,N,-5/C,N,DIFFSTIF $  
264 LABEL FINIS $  
265 END $
```

NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

3.22.2 Description of DMAP Operations for Static Aerothermoelastic Analysis with Differential Stiffness

2. GPI generates coordinate system transformation matrices, tables of grid point locations, and tables for relating internal and external grid point numbers.
4. Go to DMAP No. 256 if no grid point definition table.
6. GP2 generates Element Connection Table with internal indices.
9. PARAMR sets CSIGN=(SIGN, 0.0), where SIGN is +1.0 or -1.0 for analysis or design type run.
11. Go to DMAP No. 21 if no plot package is present.
12. PLTSET transforms user input into a form used to drive structure plotter.
14. PRTMSG prints error messages associated with structure plotter.
17. Go to DMAP No. 21 if no undeformed structure plot request.
18. PLDT generates all requested undeformed structure plots.
20. PRTMSG prints plotter data and engineering data for each undeformed plot generated.
23. GP3 generates Static Loads Table and Grid Point Temperature Table.
27. TAI generates element tables for use in matrix assembly and stress recovery.
29. Go to DMAP No. 256 and print error message if no structural elements.
33. EMG generates structural element matrix tables and dictionaries for later assembly.
36. Go to DMAP No. 39 if no stiffness matrix is to be assembled.
37. EMA assembles stiffness matrix $[K_{gg}^X]$ and Grid Point Singularity Table.
40. Go to DMAP No. 43 if no mass matrix is to be assembled.
41. EMA assembles mass matrix $[M_{gg}]$.
44. Go to DMAP No. 48 if no weight and balance request.
45. Go to DMAP No. 260 and print error message if no mass matrix exists.
46. GPWG generates weight and balance information.
47. BFP formats weight and balance information and places it on the system output file for printing.
49. Equivalence $[K_{gg}^X]$ to $[K_{gg}]$ if no general elements.
51. Go to DMAP No. 54 if no general elements.
52. SMA3 adds general elements to $[K_{gg}^X]$ to obtain stiffness matrix $[K_{gg}]$.
56. GP4 generates flags defining members of various displacement sets (USET), forms multipoint constraint equations $[R_g](u_g) = 0$ and forms enforced displacement vector $\{Y_s\}$.

RIGID FORMATS

58. Go to DMAP No. 262 and print error message if no independent degrees of freedom are defined.
61. Go to DMAP No. 63 if no free-body supports supplied, otherwise go to DMAP No. 258.
64. Go to DMAP No. 67 if general elements present.
65. GPSP determines if possible grid point singularities remain.
67. Go to DMAP No. 69 if no Grid Point Singularity Table.
68. BFP formats table of possible grid point singularities and places it on the system output file for printing.
70. Equivalence $[K_{gg}]$ to $[K_{nn}]$ if no multipoint constraints.
72. Go to DMAP No. 77 if MCE1 and MCE2 have already been executed for current set of multipoint constraints.
73. MCE1 partitions multipoint constraint equations $[R_g] = [R_m; R_n]$ and solves for multipoint constraint transformation matrix $[G_m] = -[R_m]^{-1}[R_n]$.
75. MCE2 partitions stiffness matrix

$$[K_{gg}] = \begin{bmatrix} \bar{K}_{nn} & | & K_{nm} \\ \hline K_{mn} & + & K_{mm} \end{bmatrix}$$

and performs matrix reduction

$$[K_{nn}] = [\bar{K}_{nn}] + [G_m^T][K_{mn}] + [K_{mn}^T][G_m] + [G_m^T][K_{mm}][G_m].$$

78. Equivalence $[K_{nn}]$ to $[K_{ff}]$ if no single-point constraints.
80. Go to DMAP No. 83 if no single-point constraints.
81. SCE1 partitions out single-point constraints.

$$[K_{nn}] = \begin{bmatrix} K_{ff} & | & K_{fs} \\ \hline K_{sf} & + & K_{ss} \end{bmatrix}$$

83. Equivalence $[K_{ff}]$ to $[K_{aa}]$ if no omitted coordinates.
86. Go to DMAP No. 89 if no omitted coordinates.
87. SMP1 partitions constrained stiffness matrix

$$[K_{ff}] = \begin{bmatrix} \bar{K}_{aa} & | & K_{ao} \\ \hline K_{oa} & + & K_{oo} \end{bmatrix}$$

solves for transformation matrix $[G_o] = -[K_{oo}]^{-1}[K_{oa}]$
and performs matrix reduction $[K_{aa}] = [\bar{K}_{aa}] + [K_{oa}^T][G_o]$.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

90. RMBG2 decomposes constrained stiffness matrix $[K_{aa}] = [L_{LL}][U_{LL}]$.
92. SSG1 generates non-aerodynamic static load vectors $\{P_g^{NA}\}$.
95. Go to DMAP No. 105 if no aerodynamic loads.
96. ALG generates aerodynamic load data.
102. SSG1 generates aerodynamic load vector $\{P_g^A\}$.
104. Add $\{P_g^{NA}\}$ and $\{P_g^A\}$ to form total load vector $\{P_g\}$.
106. Equivalence $\{P_g\}$ to $\{P_g^{NA}\}$ if no aerodynamic loads.
108. Equivalence $\{P_g\}$ to $\{P_L\}$ if no constraints applied.
110. Go to DMAP No. 113 if no constraints applied.
111. SSG2 applies constraints to static load vectors

$$\begin{aligned}\{P_g\} &= \left\{ \frac{\bar{P}_n}{P_m} \right\}, \quad \{P_n\} = (\bar{P}_n) + [G_m^T](P_m), \\ \{P_n\} &= \left\{ \frac{\bar{P}_f}{P_s} \right\}, \quad \{P_f\} = (\bar{P}_f) - [K_{fs}](Y_s), \\ \{P_f\} &= \left\{ \frac{P_a}{P_o} \right\} \text{ and } \{P_L\} = (P_a) + [G_o^T](P_o).\end{aligned}$$

114. SSG3 solves for displacements of independent coordinates

$$\{u_L\} = [K_{aa}]^{-1}(P_L),$$

solves for displacements of omitted coordinates

$$\{u_o^0\} = [K_{oo}]^{-1}(P_o),$$

calculates residual vector (RULV) and residual vector error ratio for independent coordinates

$$\begin{aligned}\{\delta P_L\} &= \{P_L\} - [K_{aa}]\{u_L\} \\ \epsilon_L &= \frac{\{u_L^T\}(\delta P_L)}{\{P_L^T\}(u_L)}\end{aligned}$$

and calculates residual vector (RUOV) and residual vector error ratio for omitted coordinates

$$\begin{aligned}\{\delta P_o\} &= \{P_o\} - [K_{oo}]\{u_o^0\}, \\ \epsilon_o &= \frac{\{u_o^T\}(\delta P_o)}{\{P_o^T\}(u_o^0)}\end{aligned}$$

RIGID FORMATS

117. Go to DMAP No. 120 if residual vectors are not to be printed.
118. Print residual vector for independent coordinates (RULV).
119. Print residual vector for omitted coordinates (RUVV).
121. SDR1 recovers dependent displacements

$$\{u_0\} = [G_0]\{u_1\} + \{u_0^0\} .$$

$$\begin{Bmatrix} u_0 \\ \dots \\ u_0 \end{Bmatrix} = \{u_f\} ,$$

$$\begin{Bmatrix} u_f \\ \dots \\ v_s \end{Bmatrix} = \{u_n\} ,$$

$$\{u_m\} = [G_m]\{u_n\},$$

$$\begin{Bmatrix} u_n \\ \dots \\ u_m \end{Bmatrix} = \{u_g\} ,$$

and recovers single-point forces of constraint

$$\{q_s\} = -(P_s) + [K_{fs}^T]\{u_f\} + [K_{ss}]\{v_s\}.$$

122. SDR2 calculates element forces and stresses (BEFI, BEST) and prepares load vectors, displacement vectors and single-point forces of constraint for output (BPGI, BUGVI, PUGVI, BOGI).
125. DFP formats tables prepared by SDR2 and places them on the system output file for printing.
127. Go to DMAP No. 131 if no static deformed structure plots are requested.
128. PLDT generates all requested static deformed structure plots.
130. PRTMSG prints plotter data and engineering data for each deformed plot generated.
132. TAI generates element tables for use in differential stiffness matrix assembly.
133. DSMG1 generates differential stiffness matrix $[K_{gg}^d]$.
135. Go to DMAP No. 137 if no aerodynamic loads.
136. Equivalence $\{P_g^{NA}\}$ to $\{P_g\}$ to remove aerodynamic loads from total load vector before entering differential stiffness loop. New aerodynamic loads will be generated in loop.
142. Go to next DMAP instruction if cold start or modified restart. BUTLPTDP will be altered by the Executive System to the proper location inside the loop for unmodified restarts within the loop.
143. Beginning of outer loop for differential stiffness iteration.
144. Equivalence $\{P_g\}$ to $\{P_g\}$ if no enforced displacements.
147. Equivalence $[K_{gg}^d]$ to $[K_{nn}^d]$ if no multipoint constraints.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

149. Go to DMAP No. 152 if no multipoint constraints.

150. MCE2 partitions differential stiffness matrix

$$[K_{gg}^d] = \begin{bmatrix} \bar{K}_{nn}^d & | & K_{nm}^d \\ \hline \bar{K}_{mn}^d & + & K_{mm}^d \end{bmatrix}$$

and performs matrix reduction $[K_{nn}^d] = [\bar{K}_{nn}^d] + [G_m^T][K_{mn}^d] + [K_{mn}^d][G_m]$
 $+ [G_m^T][K_{mm}^d][G_m]$.

153. Equivalence $[K_{nn}^d]$ to $[K_{ff}^d]$ if no single-point constraints.

155. Go to DMAP No. 158 if no single-point constraints.

156. SCE1 partitions out single-point constraints

$$[K_{nn}^d] = \begin{bmatrix} K_{ff}^d & | & K_{fs}^d \\ \hline \bar{K}_{sf}^d & + & K_{ss}^d \end{bmatrix}$$

159. Equivalence $[K_{ff}^d]$ to $[K_{aa}^d]$ if no omitted coordinates.

161. Go to DMAP No. 164 if no omitted coordinates.

162. SMP2 partitions constrained differential stiffness matrix

$$[K_{ff}^d] = \begin{bmatrix} \bar{K}_{aa}^d & | & K_{ao}^d \\ \hline K_{oa}^d & + & K_{oo}^d \end{bmatrix}$$

and performs matrix reduction $[K_{aa}^d] = [\bar{K}_{aa}^d] + [K_{oa}^d]^T[G_o] + [G_o]^T[K_{oa}^d]$
 $+ [G_o]^T[K_{oo}^d][G_o]$.

165. ADD $[K_{aa}^d]$ and $[K_{aa}^d].CSIGN$ to form $[K_{aa}^b]$.

166. ADD $[K_{fs}^d]$ and $[K_{fs}^d].CSIGN$ to form $[K_{fs}^b]$.

167. ADD $[K_{ss}^d]$ and $[K_{ss}^d].CSIGN$ to form $[K_{ss}^b]$.

168. Go to DMAP No. 178 if no enforced displacements.

169. MPYAD multiply $[K_{ss}^b]$ and $\{Y_s\}$ to form $\{P_{ss}\}$.

170. MPYAD multiply $[K_{fs}^b]$ and $\{Y_s\}$ to form $\{P_{fs}\}$.

171. UMERGE expand $\{P_{fs}\}$ and $\{P_{ss}\}$ to form $\{P_n\}$.

174. UMERGE expand $\{P_n\}$ to form $\{P_g^X\}$.

176. ADD $-\{P_g^X\}$ and $\{P_g\}$ to form $\{P_{gg}\}$.

177. Equivalence $\{P_{gy}\}$ to $\{P_{g1}\}$.

RIGID FORMATS

179. ADD (P_{g1}) and nothing to create (P_{go}) .
180. Copy (u_g) to (u_g^A) to initialize aerodynamic displacements.
181. RBHIG2 decomposes the combined differential stiffness matrix and elastic stiffness matrix.

$$[K_{LL}^B] = [L_{LL}^B][U_{LL}^B].$$

184. PRTPARM prints the scaled value of the determinant of the combined differential stiffness matrix and elastic stiffness matrix.
185. PRTPARM prints the scale factor (power of ten) of the determinant of the combined differential stiffness matrix and the elastic stiffness matrix.
186. Go to next DMAP instruction if cold start or modified restart. INLPTOP will be altered by the executive system to the proper location inside the loop for unmodified restarts within the loop.
187. Beginning of inner loop for differential stiffness iteration.
188. Go to DMAP No. 194 if no aerodynamic loads.
189. ALG generates aerodynamic load data.
190. Go to DMAP No. 235 if ALG fails to converge while generating aerodynamic load data.
191. SSG1 generates aerodynamic load vector (P_g^A) .
192. ADD (P_{g1}) and (P_g^A) to form total load vector (P_{g2}) .
193. SSG2 applies constraints to static load vectors

$$(P_{g2}) = \begin{pmatrix} \bar{p}_n^b \\ \bar{p}_m^b \end{pmatrix}, \quad (p_n^b) = (\bar{p}_n^b) + [G_m^T](p_m^b),$$

$$(p_n^b) = \begin{pmatrix} \bar{p}_f^b \\ \bar{p}_s^b \end{pmatrix}, \quad (p_f^b) = (\bar{p}_f^b) - [K_{fs}^d](Y_s),$$

$$(p_f^b) = \begin{pmatrix} \bar{p}_a^b \\ \bar{p}_o^b \end{pmatrix} \quad \text{and} \quad (p_a^b) = (p_a^b) + [G_o^T](p_o^b).$$

202. SSG3 solves for displacements of independent coordinates for current differential stiffness load vector

$$(u_L^b) = [K_{LL}^B]^{-1}(p_L^b)$$

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

and calculates residual vect_r. (RBULV) and residual vector error ratio for current differential stiffness load vector

$$(\delta P_{\frac{1}{k}}^b) = (P_{\frac{1}{k}}^b) - [K_{\frac{1}{k} \frac{1}{k}}^b](U_{\frac{1}{k}}^b) .$$

$$c_{\frac{1}{k}}^b = \frac{(U_{\frac{1}{k}}^b)^T (\delta P_{\frac{1}{k}}^b)}{(P_{\frac{1}{k}}^b)^T (U_{\frac{1}{k}}^b)} .$$

- 205. Go to DMAP No. 207 if residual vector for current differential stiffness solution is not to be printed.
- 206. Print residual vector for current differential stiffness solution.
- 208. SDRI recovers dependent displacements for current differential stiffness solution

$$(U_0^b) = [G_0](U_{\frac{1}{k}}^b) + (U_0^{ob}) , \quad \begin{cases} U_{\frac{1}{k}}^b \\ U_0^b \end{cases} = (U_p^b) .$$

$$\begin{cases} U_f^b \\ Y_s^b \end{cases} = (U_n^b) , \quad (U_m^b) = [G_m](U_n^b) .$$

$$\begin{cases} U_n^b \\ U_g^b \\ U_m^b \end{cases} = (U_g^b)$$

and recovers single-point forces of constraint for current differential stiffness solution

$$(q_s^b) = -(P_g^b) + [K_{sf}^b](U_f^b) + [K_{ff}^b](Y_s^b) .$$

- 210. Go to DMAP No. 212 if no aerodynamic loads.
- 211. Equivalence (U_g^b) to (U_g^A) .
- 213. ADD $-(U_g^b)$ and (U_g) to form (U_g^d) .
- 214. DSMG1 generates differential stiffness matrix $[K_{gg}^d]$.
- 216. MPYAD form load vector for inner loop iteration.

$$(P_{g_{11}}) = K_{gg}^d(U_g^b) + (P_{go})$$

- 217. ADD $(P_{g_{11}})$ and (P_g^A) to form $(P_{g_{12}})$.
- 218. DSCHK performs differential stiffness convergence checks.
- 220. Go to DMAP No. 235 if differential stiffness iteration is complete.
- 221. Go to DMAP No. 227 if additional differential stiffness matrix changes are necessary for further iteration.
- 222. Equivalence breaks previous equivalence of (P_g) to (P_{g1}) .

RIGID FORMATS

223. Equivalence $\{P_{g_{11}}\}$ to $\{P_g\}$.
224. Equivalence breaks previous equivalence of $\{P_{g1}\}$ to $\{P_{g_{11}}\}$.
225. Go to DMAP No. 187 for additional inner loop differential stiffness iteration.
226. TABPT table prints vectors $\{P_{g_{11}}\}$, $\{P_{g1}\}$, and $\{P_g\}$.
228. ADD $[\delta K_{gg}^d]$ and $[K_{gg}^d]$ to form $[K_{gg}^d]$.
230. Equivalence $\{U_g^b\}$ to $\{U_g\}$ and $[K_{gg}^d]$ to $[K_{gg}^d]$.
231. Equivalence breaks previous equivalence of $[K_{gg}^d]$ to $[K_{gg}^d]$ and $\{U_g\}$ to $\{U_g^b\}$.
233. Go to DMAP No. 143 for additional outer loop differential stiffness iteration.
234. TABPT table prints $[K_{gg1}^d]$, $[K_{gg}^d]$ and $\{U_g\}$.
237. Go to DMAP No. 241 if the total stiffness matrix is not to be saved on tape.
238. ADD $[K_{gg}]$ and $[K_{gg}^d]$ to form $[KTOTAL]$.
239. OUTPUT1 outputs $[KTOTAL]$ to tape.
240. OUTPUT1 prints the names of the data blocks on the output tape.
243. ALG generates final aerodynamic results and generates GRID and STREAML2 bulk data cards on the system punch, if requested.
244. SDR2 calculates element forces and stresses (θEFB), $\theta ESB1$) and prepares displacement vectors and single-point forces of constraint for output ($\theta UBGV1$, $\theta PUBGV1$, $\theta OBG1$) for all differential stiffness solutions.
245. OFP formats tables prepared by SDR2 and places them on the system output file for printing.
247. SDR1 recovers dependent displacements after differential stiffness loop for grid point force balance.
248. GPFDR calculates for requested sets the grid point force balance and element strain energy for output.
249. OFP formats the tables prepared by GPFDR and places them on the system output file for printing.
250. Go to DMAP No. 254 if no deformed differential stiffness structure plots are requested.
251. PLDT generates all requested deformed differential stiffness structure plots.
253. PRTMSG prints plotter data and engineering data for each deformed plot generated.
255. Go to DMAP No. 264 and make normal exit.
257. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 1 - NO STRUCTURAL ELEMENTS HAVE BEEN DEFINED.
259. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 2 - FREE BODY-SUPPORTS NOT ALLOWED.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

261. STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 4 - MASS MATRIX REQUIRED FOR WEIGHT AND BALANCE CALCULATIONS.
- 263 STATIC ANALYSIS WITH DIFFERENTIAL STIFFNESS ERROR MESSAGE NO. 5 - NO INDEPENDENT DEGREES OF FREEDOM HAVE BEEN DEFINED.

RIGID FORMATS

3.22.3 Automatic Output for Static Aerothermoelastic Analysis with Differential Stiffness

The value of the determinant of the sum of the elastic stiffness and the differential stiffness is automatically printed for each differential stiffness loading condition.

Iterative differential stiffness computations are terminated for one of five reasons. Iteration termination reasons are automatically printed in an information message. These reasons have the following meanings:

1. REASON 0 means the iteration procedure was incomplete at the time of exit. This is caused by an unexpected interruption of the iteration procedure prior to the time the subroutine has had a chance to perform necessary checks and tests.

Not much more has happened other than to initialize the exit mode to REASON 0.

2. REASON 1 means the iteration procedure converged to the EPSI θ value supplied by the user on a PARAM bulk data card. (The default value of EPSI θ is 1.0E-5.)

3. REASON 2 means iteration procedure is diverging from the EPSI θ value supplied by the user on a PARAM bulk data card. (The default value of EPSI θ is 1.0E-5.)

4. reason 3 means insufficient time remaining to achieve convergence to the EPSI θ value supplied by the user on a PARAM bulk data card. (The default value of EPSI θ is 1.0E-5.)

5. REASON 4 means the number of iterations supplied by the user on a PARAM bulk data card has been met. (The default number of iterations is 10.) Parameter values at the time of exit are automatically output as follows:

1. Parameter D θ NE: -1 is normal; + N is the estimate of the number of iterations required to achieve convergence.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

2. Parameter SHIFT: +1 indicates a return to the top of the inner loop was scheduled; -1 indicates a return to top of the outer loop was scheduled following the current iteration.
3. Parameter DSEPSI: the value of the ratio of energy error to total energy at the time of exit.

RIGID FORMATS

3.22.4 Case Control Deck DTI Table and Parameters for Static Aerothermoelastic Analysis with Differential Stiffness

The following items relate to subcase definition and data selection for Static Aerothermoelastic Analysis with Differential Stiffness:

1. The Case Control Deck must contain two subcases.
2. A static loading condition must be defined above the subcase level with a LOAD, TEMPERATURE(LOAD), or DEFORM selection, unless all loading is specified by grid point displacements on SPC cards.
3. An SPC set must be selected above the subcase level unless all constraints are specified on GRID cards.
4. Output requests that apply only to the linear solution must appear in the first subcase.
5. Output requests that apply only to the solution with differential stiffness must be placed in the second subcase.
6. Output requests that apply to both solutions, with and without differential stiffness may be placed above the subcase level.
7. Aerodynamic input for the Aerodynamic Load Generator (ALG) module is input via data block ALGDB. This data block must be input using Direct Table Input (DTI) bulk data cards. For a detailed description of the ALGDB data block input see Section 1.15.3.1 of the User's Manual.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

The following output may be requested for Static Aerothermoelastic Analysis with Differential Stiffness:

1. Nonzero Components of the applied static load for the linear solution at selected grid points.
2. Displacement and nonzero components of the single-point forces of constraint, with and without differential stiffness, at selected grid points.
3. Forces and stresses in selected elements, with and without differential stiffness.
4. Undeformed and deformed plots of the structural model.
1. GRDPNT - optional - a positive integer value of this parameter will cause the Grid Point Weight Generator to be executed and the resulting weight and balance information to be printed.
2. WTMASS - optional - the terms of the mass matrix are multiplied by the real value of this parameter when they are generated in EMG.
3. IRES - optional - a positive integer value of this parameter will cause the printing of the residual vectors following the execution of SSG3.
4. CQUPMASS, CPBAR, CPRD, CPQUAD1, CPQUAD2, CPTRIAL, CPTRIA2, CPTUBE, CPQDPLT, CPTRPLT, CPTRBSC - optional - these parameters will cause the generation of coupled mass matrices rather than lumped mass matrices for all bar elements, rod elements, and plate elements that include bending stiffness.
5. BETAD - optional - the integer value of this parameter is the assumed number of iterations for the inner loop in shift decisions for iterated differential stiffness. The default value is 4 iterations.
6. NT - optional - the integer value of this parameter limits the maximum number of iterations. The default value is 10 iterations.

RIGID FORMATS

7. EPS10 - optional - the real value of this parameter is used to test the convergence of iterated differential stiffness. The default value is 10^{-5} .
8. APRESS - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic pressures. A negative value (the default) will suppress the generation of aerodynamic pressure loads.
9. ATEMP - optional in static aerothermoelastic analysis. A positive integer value will generate aerodynamic temperature loads. A negative value (the default) will suppress the generation of aerodynamic thermal loads.
10. STREAML - optional in static aerothermoelastic analysis. STREAML=1 causes the punching of STREAML1 bulk data cards. STREAML = 2 causes the punching of STREAML2 bulk data cards. STREAML=3 causes both STREAML1 and STREAML2 cards to be punched. The default value, -1, suppresses punching of any cards.
11. PGEOM - optional in static aerothermoelastic analysis. PGEOM=1 causes the punching of GRID bulk data cards. PGEOM=2 causes the punching of GRID, CTRIA2 and PTRIA2 bulk data cards. PGEOM=3 causes the punching of GRID cards and the modified ALGDB table on DTI cards. The default, -1, suppresses punching of any cards.
12. IPRT - optional in static aerothermoelastic analysis. If IPRT > 0, then intermediate print will be generated in the ALG module based on the print option in the ALGDB data table. If IPRT = 0 (the default), no intermediate print will be generated. (IPRTCI, IPRTCL, IPRTCF)
13. SIGN - optional in static aerothermoelastic analysis. Controls the type of analysis being performed. SIGN = 1.0 for a standard analysis. SIGN = -1.0 for a design analysis. The default is 1.0.
14. ZORIGN, FXCOOR, FYCOOR, FZCOOR - optional in static aerothermoelastic analysis. These are modification factors. The defaults are ZORIGN = 0.0, FXCOOR = 1.0, FYCOOR = 1.0, and FZCOOR = 1.0.

STATIC AEROTHERMOELASTIC ANALYSIS WITH DIFFERENTIAL STIFFNESS

15. KTOUT - optional in static aerothermoelastic analyses. A positive integer of this parameter indicates that the user wants to save the total stiffness matrix on tape (GINO file INPT) via the OUTPUT1 module in the rigid format. The default is -1.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

3.23 COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

3.23.1 DMAP Sequence For Compressor Blade Cyclic Modal Flutter Analysis

RIGID FORMAT UMAP LISTING
SERIES 0

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

OPTIONS IN EFFECT: GU ERR=2 NOLIST NODECK NOREF NOUSCAR

1 BEGIN AERO NU,9 COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS \$

2 FILE PHHL=APPEND/AJL=APPEND/F SAVE=APPEND/CASEYY=APPEND/CLAMAL=APPEND/UVG=APPEND/QHHL=APPEND \$

3 **(GP1)** GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/V,N,LUSET/ V,N,NOGPDT \$

4 SAVE LUSET,NOGPDT \$

5 **(COND)** ERON1,NOGPDT \$

6 CHKPNT GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL \$

7 PURGE U1JE,U2JE/NOJJE \$

8 **(GP2)** GEOM2,LQEXIN/ECT \$

9 CHKPNT ECT \$

10 **(GP3)** GEOM3,LQEXIN,GEOM2/,GPTT/V,N,NOGRAV \$

11 CHKPNT GPTT \$

12 **(TAI)** ECT,EPT,BGPDT,SIL,GPDT,CSTM/EST,GEI,GPECT,/V,N,LUSET/ V,N,NUSIMP/C,N,I/V,N,NUGENL/V,N,GENEL \$

13 SAVE NUGENL,NUSIMP,GENEL \$

14 **(COND)** ERRJK1,NOSIMP \$

15 PURGE UGPST/GENEL \$

16 CHKPNT EST,GPLCT,GEI,UGPST \$

17 PARAM //C,N,ADD/V,V,NUKGUX/C,N,I/C,N,O \$

18 PARAM //C,N,ADD/V,V,NUKGUX/C,N,I/C,N,O \$

19 PARA1 // C,N,NUP / V,Y,KGGIN=-1 \$

20 **(COND)** JMPKGGIN,KGGIN \$

21 **(PARAY)** //C,N,ADD / V,N,NOKUGX /C,N,-1 /C,N,O \$

22 **(INPUTT)** / KGGIN,,,/,Y,LOCATION=-1 /C,Y,INPUTUNIT=0 \$

RIGID FORMATS

RIGID FORMAT DMAP LISTING SERIES 0

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

23 **EQUIV** KGGIN,KGGX \$
24 CHKPNT KGGX \$
25 LABEL JMPKGGIN \$
26 **EMC** EST,CSTM,MPT,GIT,GEOM2,/KELM,KUICL,HELM,MDICT,,/V,N,NOKGGX/ V,
N,NU,1GG/C,N,/C,N,/C,Y,COUPMASS/C,Y,CPUAR/C,Y,CPRUD/ C,Y,
CPQUAD1/C,Y,PQUAD1/C,Y,CPTRIAL/C,Y,CPTRIAZ/C,Y,CPTUBE/C,Y,
CPQDPLT/C,Y,CPTRPL1/C,Y,CPTRBSC \$
27 SAVE NOKGGX,NUMGG \$
28 CHKPNT KELM,KUICL,HELM,MDICT \$
29 **CUND** JMPKGGX,NOKGGX \$
30 **EMA** GPECT,KUICL,KELM/KGGX,GPST \$
31 CHKPNT KGGX,GPST \$
32 LABEL JMPKGGX \$
33 **CUND** ERROR1,NUMGG \$
34 **EMA** GPECT,MDICT,HELM/MUG,/C,N,-1/C,Y,WTMASS=1.0 \$
35 CHKPNT MGG \$
36 **CUND** LGPHG,GRDPNT \$
37 **GPHG** BGPDT,CSTM,EQEWIN,MJC/SWPNG/V,Y,GRDPNT=-1/C,Y,WTMASS \$
38 **GFP** OGPNG,...,/ \$
39 LABEL LGPHG \$
40 **EQUIV** KGGX,KGG/NOGENL \$
41 CHKPNT KGG \$
42 **CUND** LBL11,NOGENL \$
43 **SMAS** GEI,KGGX/KGG/V,N,IUSET/V,N,NOGENL/V,N,NOSIMP \$
44 CHKPNT KGG \$
45 LABEL LBL11 \$
46 **GP4** CASECC,GEUM4,EQEWIN,SIL,GPDT,BGPDT,CSTM/RG,,IUSET,ASSET/ V,N,

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES 0

AERO APPROXACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

```
LUSET/V,N,MPCF1/V,N,MPCF2/V,N,SINGLE/V,N,UMIT/V,N,REACT/C,N,O/  
V,N,REPEAT/V,N,NOSET/V,N,NUL/V,N,NOA/C,Y,SUBID $  
  
47 SAVE MPCF1,SINGLE,UMIT,REACT,NOSET,MPCF2,REPEAT,NCL,NOA $  
48 PARAY //C,N,NJT/V,N,REACDATA /V,N,REACT $  
49 COUNU ENRUR5,REACDATA $  
50 PURGE GM,GMD/MPCF1/GU,GUU/OMIT/KFS,OPC/SINGLE $  
51 MPCYC GEUM4,EQEXIN,USET /CYCO/ V,Y,CTYPE / V,N,NUGO $  
52 SAVE NUGO $  
53 CHKPNT CYCU $  
54 COUNU ENRJR6,NUGO $  
55 COUNU LBL4,LEVEL $  
56 GPSP GPL,GPST,USET,SIL/UGPST/V,N,NOGPST $  
57 SAVE NOGPST $  
58 COUNU LBL4,NOGPST $  
59 UFP UGPST,.,.,./ $  
60 LABEL LBL4 $  
61 EQUIV KGG,KNN/MPCF1/MGG,MNN/MPCF1 $  
62 CHKPNT KNN,MNN $  
63 COUNU LBL2,MPLFI $  
64 MCEL USET,RG/GM $  
65 CHKPNT GM $  
66 MPCF2 USET,GM,KGG,MGG,,/KNN,MNN,, $  
67 CHKPNT KNN,MNN $  
68 LABEL LBL2 $  
69 EQUIV KNN,KFF/SINGLE/MNN,MFF/SINGLE $  
70 CHKPNT KFF,MFF $
```

RIGID FORMATS

RIGID FORMAT DMAP LISTING SERIES 3

AERU APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

71	CUND	LBL3,SINGLE \$
72	SCEI	USET,KNN,MNN,,/KFF,KFS,,MFF,, \$
73	CHKPNT	KFF,KFS,MFF \$
74	LABEL	LBL3 \$
75	EQUIV	KFF-KAA/UMIT/ MFF ,MAA/UMIT \$
76	CHKPNT	KAA,MAA \$
77	COUN	LBL5,UMIT \$
78	SMP1	USET,KFF,,,/GU,KAA,KCD,LUU,,,,, \$
79	CHKPNT	GU,KAA \$
80	SMP2	USET,GU,MFF/MAA \$
81	CHKPNT	MAA \$
82	LABEL	LBL5 \$
83	UPC	DYVAMICS,GPL,SIL,USET/GPLD,SILD,USETD,TFPOUL,,,,,EED,EGDYN/V, N,LUSET/V,N,LUSETD/V,N,NUTIL/V,N,NUDLT/V,N,NUPSDL/V,N,NOFRL/V, N,VONLT/V,N,NUTRL/V,N,NUEED/C,N,/V,N,NJUE \$
84	SAVE	LUSETD,NUUE,NUEED \$
85	CUND	ERRJR2,NOED \$
86	EQUIV	GU,GU/NUUE/SM,GMD/NCUE \$
87	CYCTZ	CYCD,KAA,MAA,,, /KKK,MKK,,, / C,N,FORE / V,Y,NEIGS=-1 /V,Y, KINDEX=-1 / V,Y,CYCSEQ=-1 / C,N,I / V,N,NOGO \$
88	SAVE	NUGU \$
89	CHKPNT	KKK,MKK \$
90	CUND	ERRJR6,NOGU \$
91	READ	KKK,MKK,,,EED,,CASECC / LAMK,PHIK, ,OEIGS / C,N,MODES /V,N, NEIGV \$
92	SAVE	NEIGV \$
93	CHKPNT	LAMK,PHIK,MI,UEIGS \$

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT UMAP LISTING
SERIES 0

AERO APPROXIM, RIGID FORMAT 9

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

```
94 PARAM    //C,N,MPY / V,N,CARDNO / C,N,O / C,N,O $  
95 (UFP)    UELGS,LAHK,,, / V,N,CARDNO $  
96 SAVE     CARDNO $  
97 (COND)   ERROR4,NEIGV $  
98 (LC12)   CYCD,,,PHIK,L4MK /,,PHIA,LAMA / C,N,BACK / V,Y,NGECS /V,Y,  
            KINDEX / V,Y,CYCSEQ / C,N,I / V,N,NUO $  
99 SAVE     NUO $  
100 CHKPNT  LAMA,PHIA $  
101 (COND)   ERROR4,NUO $  
102 (S01)    USET,,,PHIA,,,GU,GM,,,N,S,, / PHIG,, / C,N,I / C,N,REIG $  
103 (SUR2)   CASECC,CST4,4PT,DIT,EQEXIN,SIL,,,BGPDT,LAMA,,PHIG,EST,, / ..  
            OPHIG,,, / C,N,REIG $  
104 (UFP)    OPHIG,,, / V,N,CARDNO $  
105 SAVE     CARDNO $  
106 (APC0)   EDT,USET,BGPDT,CST4,EQEXIN,GM,GO / AERO,ACPT,FLIST,GTKA,PVECT/  
            V,N,VK/V,N,NJ/V,Y,AIRMACH/V,Y,MAXMACH/V,Y,IREF/V,Y,MTYPE/V,N,  
            NEIGV/V,Y,KINDEX=-1 $  
107 SAVE     NK,NJ $  
108 CHKPNT  AERO,ACPT,FLIST,GTKA,PVECT $  
109 (PARTN)  PHIA,PVECT, / PHIAX,,, / C,N,I $  
110 (SMPYAO) PHIAX,4AA,PHIAx,,, / MI / C,N,3/C,N,I/C,N,I/C,N,O/C,N,I $  
111 (MTRXIV) CASECC,MATPDL,EQDYN,,TFPUCL/K2PP,M2PP,B2PP/V,N,LUS ETD/V,N,  
            NUK2PP/V,N,NJM2PP/V,N,NUB2PP $  
112 SAVE     NUK2PP,NUM2PP,NUB2PP $  
113 PURGE   K2DD/NUK2PP/M2DD/NUM2PP/B2DD/NOB2PP $  
114 (EQUIV)  M2PP,42DD/NUSET/B2PP,B2DD/NOSET/K2PP,K2DD/NOSET $  
115 CHKPNT  K2PP,M2PP,B2PP,K2DD,M2DD,B2DD $  
116 (GKAU)   USETD,GM,GO,,,K2PP,M2PP,B2PP/,,,GMD,GDD,K2DD,M2DD,B2DD/C,N,
```

RIGID FORMATS

RIGID FORMAT DMAP LISTING
SERIES U

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

CMPLEV/C,N,DI SP/C,N,MODAL/C,N,O,O/C,N,O,O/C,N,D,O/V,N,NOK2PP/V,
N,NO42PP/V,N,NUB2PP/V,N,MPCFI/V,N,SINGLE/V,N,UMIT/V,N,NOUE/C,
N,-1/C,N,-1/C,N,-1/C,N,-1 \$

117 CHKPNT K2DD,M2DD,B2DD,GOU,GMD \$

118 GRAY USETJ,PHIAK,M1,LAMK,UTT,M2DD,B2DD,K2DD,CASECC / MMH,BMH,KMH,
PHIDH / V,N,NUUE/C,Y,LMUDE S=99999/C,Y,LFREQ=0.0/C,Y,HFREQ=0.0/
V,N,NU42PP/V,N,NOB2PP/V,N,NUK2PP/V,N,NONCUP/V,N,FMUDE/C,Y,
KDAMP=-1 \$

119 SAVE NUNCUP,FMJDE \$

120 CHKPNT MMH,BMH,KMH,PHIDH \$

121 PAKML PCDB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NUPCDU \$

122 PURGE PLTSEIX,PLTPAK,GPSETS,LLSETS / NOPCUB \$

123 CUND P2,JUPCUB \$

124 PLTSET PCUB,EQDYN,ECT / PLTSETX,PLTPAR,UPSETS,ELSETS / V,N,NSILL / V,N,
JUMPPLOT=-1 \$

125 SAVE NSILL,JUMPPLOT \$

126 PRIMSG PLTSETX // \$

127 PARAM //C,N,MPY/V,N,PLTFLG/C,N,I/C,N,I \$

128 PARAM //C,N,MPY/V,N,PFIL/C,N,O/C,N,O \$

129 CUND P2,JUMPPLOT \$

130 PLUT PLTPAR,UPSETS,ELSETS,CASECC,BGPDT,EQDYN,,, / PLOTXI/V,N,NSILL/
V,N,LUSET/V,N,JUMPPLOT/V,N,PLTFLG/V,N,PFIL \$

131 SAVE JUMPPLOT,PLTFLG,PFIL \$

132 PRIMSG PLUTXI // \$

133 LABEL P2 \$

134 CUND ERROR2,NUEDD \$

135 PARAM //L,J,AUD/V,N,DESTRY/C,N,O/C,N,I \$

136 AMG AERU,ACPT/AJL,SKJ,DLJK,DZJK/V,N,NK/V,N,NJ/V,N,DESTRY \$

137 SAVE DESTRY \$

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT DMAP LISTING
SERIES U

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

138 CMKPNT AJJL,SKJ,D1JK,D2JK \$
139 CUND NUDJE,NUDJE \$
140 INPUT /D1JE,D2JE,,,/C,Y,POSITION=-1/C,Y,UNETNUM=11/ C,Y,USRLABEL=
TAPEID \$
141 LABEL NUDJE \$
142 PARAM //C,N,ADD/V,N,XQHHL/C,N,L/C,N,O \$
143 AMP AJJL,SKJ,D1JK,D2JK,UTKA,PH1DH,D1JE,D2JE,USETD,AERO/QHHL,QJHL/V,
N,NUUE/V,N,XJHHL \$
144 SAVE XQHHL \$
145 CMKPNT QHHL,QJHL \$
146 PARAM //C,N,4PY/V,N,NUP/C,N,-1/C,N,I \$
147 PARAM //C,N,4PY/V,N,NOP/C,N,L/C,N,I \$
148 PARAM //C,N,MPY/V,N,NOH/C,N,O/C,N,I \$
149 PARAM //C,N,4PY/V,N,FLOOP/V,Y,NUDJE=-1/C,N,O \$
150 JUMP LOOPTOP \$
151 LABEL LOOPTOP \$
152 FAIL KHH,BHH,MHH,JHHL,CASECC,FLIST/FSAVE,KXHH,BXHH,MXHH/V,N,FLOOP/V,
N,TSTART \$
153 SAVE FLOOP,TSTART \$
154 CEAU KXHH,BXHH,MXHH,FED,CASELC/PH1H,CLAMA,UCEIGS/V,N,EIGVS \$
155 SAVE EIGVS \$
156 CUND LBLZAP,EIGVS \$
157 CUND LBL16,NUH \$
158 VDR CASECC,EQDYN,USETD,PH1H,CLAMA,,/OPHIH,/C,N,CEIGEN/C,N,MODAL/C,
N,123/V,N,NUH/V,N,NUP/V,N,FMODE \$
159 SAVE NUH,NUP \$
160 CUND LBL16,NUH \$

RIGID FORMATS

RIGID FORMAT DMAP LISTING SERIES J

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN DMAP COMPILER - SOURCE LISTING

161 **UFF** OPHIH,,,./V,N,CARDNO \$
162 SAVE CARUNU \$
163 LABEL LBL16 \$
164 **FAZ** PHIHL,CLAMA,FSAVE/PHIHL,CLAMAL,CASEYY,UVG/V,N,TSTART/C,Y,VREF=1.0/C,Y,PRINT=YFSB \$
165 SAVE TSTART \$
166 CKPNT PHIHL,CLAMAL,CASEYY,UVG \$
167 **CONU** CONTINUE,TSTART \$
168 LABEL LBLZAP \$
169 **COND** CONTINUE,FLOOP \$
170 REPI LOOPTOP,100 \$
171 **JUMP** ERRJR3 \$
172 LABEL CONTINUE \$
173 CHKPNT UVG \$
174 PARAM XYCUB//C,N,PRES/C,N,/C,N,/C,N,/V,N,NOXYCDB \$
175 **COND** NOXYOUT,NOXYCDB \$
176 **XYTRAY** XYCUB,UVG,,,./XYPLTCE/C,N,UVG/C,N,PSET/V,N,PFILE/V,N,CARDNO \$
177 SAVE PFILE,CARUNU \$
178 **XYPLJ** XYPLICE// \$
179 LABEL NOXYOUT \$
180 PARAM //C,N,AND/V,N,PJUMP/V,N,NOP=-1//N,JMPPLT \$
181 **COND** FINIS,PJUMP \$
182 **MUDACC** CASEYY,CLAMAL,PHIHL,CASECC,,/CLAMAL1,CPHIHL,CASEZZ,,/C,N,CEIGN \$
183 **CCR1** CPHIHL,PHIOH/CPHID \$
184 CHKPNT CPHIU \$

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

RIGID FORMAT UMAP LISTING
SERIES 3

AERU APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASTRAN UMAP COMPILER - SOURCE LISTING

185 **EQUIV** CPHID,CPHIP/NDA \$
186 **CUND** LBL14,NUA \$
187 **SCK1** USETO,,CPHID,,,GUD,GMD,,KFS,,/CPHIP,,QPC/C,N,I/C,N,DYNAMICS \$
188 LABEL LBL14 \$
189 CHKPNT CPHIP,QPC \$
190 **EQUIV** CPHID,CPHIA/NUUE \$
191 **CUND** LBLNUE,NGUE \$
192 **VEC** USETO/RP/C,N,D/C,N,A/C,N,E \$
193 **PAKIN** CPHID,,RP/CPHIA,,,/C,N,I/C,N,3 \$
194 LABEL LBLNUE \$
195 **SCR2** CASE22,CSTM,MPT,DT,EQVYN,SILD,,,BGPDT,CLAMALI,QPC,CPHIP,EST,,/
,UQPC1,UCPHIP,UESCI,UEFL1,PLPHIP/C,N,CFIGN \$
196 CHKPNT PCPHIP \$
197 **JFP** UCCHIP,UQPC1,UESCI,UEFC1,,//V,N,CARDNO \$
198 **CUND** P3,JUMPPLOT \$
199 **PLUT** PLTPAR,GP!TS,ELSEIS,CASE22,BGPDT,EQDYN,SILD,,PCPHIP,,/PLUTX3/
V,N,NSIL1/ V,LUSET/V,N,JUMPPLOT /V,N,PLTFLG/V,N,PFILE \$
200 **PRTHSG** PLUTX3// \$
201 LABEL P3 \$
202 **JUMP** FINIS \$
203 LABEL ERROR1 \$
204 **PRTPAK1** //C,N,-1/C,N,FSUBSCN \$
205 LABEL ERROR2 \$
206 **PRTPARM** //C,N,-2/C,N,FSUBSCN \$
207 LABEL ERROR3 \$
208 **PRTPARM** //C,N,-3/C,N,FSUBSCN \$

RIGID FORMATS

RIGID FORMAT UMAP LISTING
SERIES 0

AERO APPROACH, RIGID FORMAT 9

LEVEL 2.0 NASIRAN UMAP COMPILER - SOURCE LISTING

```
209 LABEL    ERR0K4 $  
210 (PRTPAKM) //C,1,-4/C,N,F SUBSUN $  
211 LABEL    ERR0K5 $  
212 (PRTPAKM) // C,N,-4 / C,N,CYCMODES $  
213 LABEL    ERR0K6 $  
214 (PRTPAKM) // C,N,-5 / C,N,CYCMODES $  
215 LABEL    FINIS $  
216 ENC      $
```

0000 ERRORS FOUND - EXECUTE NASTRAN PROGRAM**

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

3.23.2 Description of DMAP Operations for Compressor Blade Cyclic Modal Flutter Analysis

3. GP1 generates coordinate system transformation matrices, tables of grid point locations, and tables for relating internal and external grid point numbers.
5. Go to DMAP No. 203 and print error message if no grid points are present.
8. GP2 generates Element Connection Table with internal indices.
10. GP3 generates Static Loads Table and Grid Point Temperature Table.
12. TA1 generates element tables for use in matrix assembly and stress recovery.
14. Go to DMAP No. 203 and print error message if no elements have been defined.
20. Go to DMAP No. 25 if stiffness matrix is not user input.
21. Set parameter NOKGGX = -1 so that the stiffness matrix will not be generated in DMAP No. 26.
22. INPUT1 reads the user supplied stiffness matrix from tape (GINO file INPT).
23. Equivalence $[K_{gg}^X]$ to $[K_{gg}^{IN}]$.
26. EMG generates structural element matrix tables and dictionaries for later assembly.
29. Go to DMAP No. 32 if no stiffness matrix is to be assembled.
30. EMA assembles stiffness matrix $[K_{gg}^X]$ and Grid Point Singularity Table.
33. Go to DMAP No. 203 and print error message if no mass matrix exists.
34. EMA assembles mass matrix $[M_{gg}]$.
36. Go to DMAP No. 39 if no weight and balance request.
37. GPWG generates weight and balance information.
38. WFP formats weight and balance information and places it on the system output file for printing.
40. Equivalence $[K_{gg}^X]$ to $[K_{gg}]$ if no general elements.
42. Go to DMAP No. 45 if no general elements.
43. SMA3 adds general elements to $[K_{gg}^X]$ to obtain stiffness matrix $[K_{gg}]$.
46. GP4 generates flags defining members of various displacement sets (USET), forms multipoint constraint equations $[R_g](u_g) = 0$.
49. Go to DMAP No. 211 and print error message if free-body supports are present.
51. GPCYC prepares segment boundary table.
54. Go to DMAP No. 213 and print error message if CYJOIN data is inconsistent.

RIGID FORMATS

55. Go to DMAP No. 60 if general elements present.
56. GPSP determines if possible grid point singularities remain.
58. Go to DMAP No. 60 if no grid point singularities remain.
59. DFP formats the table of possible grid point singularities and places it on the system output file for printing.
61. Equivalence $[K_{gg}]$ to $[K_{nn}]$ and $[M_{gg}]$ to $[M_{nn}]$ if no multipoint constraints.
63. Go to DMAP No. 68 if MCE1 and MCE2 have already been executed for current set of multipoint constraints.
64. MCE1 partitions multipoint constraint equations $[R_g] = [R_m; R_n]$ and solves for multipoint constraint transformation matrix $[G_m] = -[R_m]^{-1}[R_n]$.
66. MCE2 partitions stiffness and mass matrices

$$[K_{gg}] = \begin{bmatrix} \bar{K}_{nn} & | & K_{nm} \\ \hline \hline K_{mn} & | & K_{mm} \end{bmatrix} \quad \text{and} \quad [M_{gg}] = \begin{bmatrix} \bar{M}_{nn} & | & M_{nm} \\ \hline \hline M_{mn} & | & M_{mm} \end{bmatrix}$$

and performs matrix reductions

$$\begin{aligned} [K_{nn}] &= [\bar{K}_{nn}] + [G_m^T][K_{mn}] + [K_{mn}^T][G_m] + [G_m^T][K_{mm}][G_m] \text{ and} \\ [M_{nn}] &= [\bar{M}_{nn}] + [G_m^T][M_{mn}] + [M_{mn}^T][G_m] + [G_m^T][M_{mm}][G_m]. \end{aligned}$$

69. Equivalence $[K_{nn}]$ to $[K_{ff}]$ and $[M_{nn}]$ to $[M_{ff}]$ if no single-point constraints.
71. Go to DMAP No. 74 if no single-point constraints.
72. SCE1 partitions out single-point constraints.

$$[K_{nn}] = \begin{bmatrix} K_{ff} & | & K_{fs} \\ \hline \hline K_{sf} & | & K_{ss} \end{bmatrix} \quad \text{and} \quad [M_{nn}] = \begin{bmatrix} M_{ff} & | & M_{fs} \\ \hline \hline M_{sf} & | & M_{ss} \end{bmatrix}$$

75. Equivalence $[K_{ff}]$ to $[K_{aa}]$ and $[M_{ff}]$ to $[M_{aa}]$ if no omitted degrees of freedom.
77. Go to DMAP No. 82 if no omitted coordinates.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

78. SMP1 partitions constrained stiffness matrix

$$[K_{ff}] = \begin{bmatrix} K_{aa} & | & K_{ao} \\ \hline | & & | \\ K_{oa} & | & K_{oo} \end{bmatrix}$$

and solves for transformation matrix $[G_o] = -[K_{oo}]^{-1}[K_{oa}]$

and performs matrix reduction $[K_{aa}] = [\bar{K}_{aa}] + [K_{oa}^T][G_o]$.

80. SMP2 partitions constrained mass matrix

$$[M_{ff}] = \begin{bmatrix} M_{aa} & | & M_{ao} \\ \hline | & & | \\ M_{oa} & | & M_{oo} \end{bmatrix}$$

and performs matrix reduction

$$[M_{aa}] = [M_{aa}] + [M_{oa}^T][G_o] + [G_o^T][M_{oo}][G_o] + [G_o^T][M_{oa}]$$

- 83. DPD generates flags defining members of various displacement sets used in dynamic analysis (USETD), tables relating internal and external grid point numbers, including extra points introduced for dynamic analysis, and prepares Transfer Function Pool and Eigenvalue Extraction Data.
- 85. Go to DMAP No. 205 and print error message if no Eigenvalue Extraction Data.
- 86. Equivalence $[G_o]$ to $[G_o^d]$ and $[G_m]$ to $[G_m^d]$ if no extra points introduced for dynamic analysis.
- 87. CYCT2 transforms matrices from symmetric components to solution set.
- 90. Go to DMAP No. 213 and print error message if CYCT2 error was found.
- 91. READ extracts real eigenvalues from the equation

$$[K_{kk} - \lambda M_{kk}]\{u_k\} = 0$$

and normalizes eigenvectors according to one of the following user requests:

- 1) Unit value of selected coordinate
- 2) Unit value of largest components
- 3) Unit value of generalized mass.

- 95. OFP formats eigenvalues and summary of eigenvalue extraction information and places them on the system output file for printing.
- 97. Go to DMAP No. 209 and exit if no eigenvalues found.
- 98. CYCT2 finds symmetric components of eigenvectors from solution set eigenvectors.

RIGID FORMATS

101. Go to DMAP No. 213 and print error message if CYCT2 error was found.
102. SDR1 recovers dependent components of the eigenvectors

$$\{\phi_o\} = [G_o]\{\phi_a\} , \quad \left\{ \begin{array}{c} \phi_a \\ \phi_f \\ \phi_o \end{array} \right\} = \{\phi_f\} .$$

$$\left\{ \begin{array}{c} \phi_f \\ \phi_s \end{array} \right\} = \{\phi_n\} , \quad \{\phi_m\} = [G_m]\{\phi_n\} .$$

$$\left\{ \begin{array}{c} \phi_n \\ \phi_g \\ \phi_m \end{array} \right\} = \{\phi_g\}$$

103. SDR2 prepares eigenvectors for output (OPHIG).
 104. OFP formats tables prepared by SDR2 and places them on the system output file for printing.
 105. APDB processes the aerodynamic data cards from EDT. AERO and ACPT reflect the aerodynamic parameters. PVECT is a partitioning vector and GTKA is a transformation matrix between aerodynamic (K) and structural (a) degrees of freedom.
 109. PARTN partitions the eigenvector into all sine or all cosine components.
 110. SMPYAD calculates modal mass matrix
- $$[M] = [\phi_a^x]^T [M_{aa}] [\phi_a^x]$$
111. MTRXII selects the direct input matrices $[K_{pp}^2]$, $[M_{pp}^2]$, and $[B_{pp}^2]$.
 114. Equivalence $[M_{pp}^2]$ to $[M_{dd}^2]$, $[B_{pp}^2]$ to $[B_{dd}^2]$ and $[K_{pp}^2]$ to $[K_{dd}^2]$ if no constraints applied.
 116. GKAD applies constraints to direct input matrices $[K_{pp}^2]$, $[M_{pp}^2]$, and $[M_{dd}^2]$, and $[B_{dd}^2]$ (see Section 9.3.3 of the Theoretical Manual) and forms $[G_{md}]$ and $[G_{od}]$.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

118. GKAM selects eigenvectors to form $[\phi_{dh}]$ and assembles stiffness, matrices and damping matrices in modal coordinates:

$$[K_{hh}] = \begin{bmatrix} k_1 & 0 \\ 0 & 0 \end{bmatrix} + [\phi_{dh}^T][K_{dd}^2][\phi_{dh}] .$$

$$[M_{hh}] = \begin{bmatrix} m_1 & 0 \\ 0 & 0 \end{bmatrix} + [\phi_{dh}^T][M_{dd}^2][\phi_{dh}] .$$

$$[B_{hh}] = \begin{bmatrix} b_1 & 0 \\ 0 & 0 \end{bmatrix} + [\phi_{dh}^T][B_{dd}^2][\phi_{dh}] .$$

where

KDAMP = 1

m_i = modal masses

$b_i = m_i 2\pi f_i g(f_i)$

$k_i = m_i 4\pi^2 f_i^2$

KDAMP = -1 (default)

m_i = modal masses

$b_i = 0$

$k_i = (1+ig(f_i)) 4\pi^2 f_i^2 m_i$

123. Go to DMAP No. 133 if no plot package is present.
124. PLTSET transforms user input into a form used to drive structure plotter.
126. PRTMSG prints error messages associated with structure plotter.
129. GO to DMAP No. 133 if no undeformed aerodynamic structure plot request.
130. PL0T generates all requested undeformed structure plots.
132. PRTMSG prints plotter data and engineering data for each undeformed aerodynamic plot generated.
134. Go to DMAP No. 205 and print error message if no Eigenvalue Extraction Data.
136. AMG forms the aerodynamic matrix list $[A_{jj}]$, the area matrix $[S_{kj}]$, and the downwash coefficients $[D_{jk}^1]$ and $[D_{jk}^2]$.
139. Go to DMAP No. 141 if no user-supplied downwash coefficients.
140. INPUTT2 provides the user-supplied downwash factors due to extra points ($[D_{je}^1]$, $[D_{je}^2]$).

RIGID FORMATS

143. ANP computes the aerodynamic matrix list related to the modal coordinates as follows:

$$[\Phi_{dh}] = \begin{bmatrix} \Phi_{af} & \Phi_{ae} \\ \cdots & \cdots \\ \Phi_{ei} & \Phi_{ee} \end{bmatrix}$$

$$[G_{ki}] = [G_{ka}^T]^T [\Phi_{ei}]$$

$$[D_{jh}^1] = [D_{ji}^1 \mid D_{je}^1]$$

$$[D_{jk}^1] = [D_{jk}^1]^T [G_{ki}]$$

$$[D_{jh}^2] = [D_{ji}^2 \mid D_{je}^2]$$

$$[D_{jk}^2] = [D_{jk}^2]^T [G_{ki}]$$

For each (m,k) pair:

$$[D_{jh}] = [D_{jh}^1] + (k[D_{jh}^2])$$

for each group:

$$[Q_{jh}] = [A_{jj}^T]^{-1} \text{ group } [D_{jh}] \text{ group}$$

$$[Q_{kh}] = [S_{kj}] [Q_{jh}]$$

$$[Q_{ih}] = [G_{ki}]^T [Q_{kh}]$$

$$[Q_{hh}] = \begin{bmatrix} Q_{ih} \\ Q_{eh} \end{bmatrix}$$

149. PARAM initializes the flutter loop counter (FL00P) to zero.

150. Go to next DMAP instruction if cold start or modified restart. L0OPT0P will be altered by the Executive System to the proper location inside the loop for unmodified restarts within the loop.

151. Beginning of loop for flutter.

152. FAI computes the total aerodynamic mass matrix $[M_{hh}^x]$, the total aerodynamic stiffness matrix $[K_{hh}^x]$ and the total aerodynamic damping matrix $[B_{hh}^x]$ as well as a looping table FSAVE. For the K-method

$$M_{hh}^x = (k^2/b^2) M_{hh} + (\rho/2) Q_{hh} ,$$

$$K_{hh}^x = K_{hh} ,$$

$$B_{hh}^x = 0$$

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

154. CEAD extracts complex eigenvalues from the equation

$$[M_{hh}^X p^2 + B_{hh}^X p + K_{hh}^X] (\phi_h) = 0$$

and normalizes eigenvectors to unit magnitude of largest component.

156. Go to DMAP No. 168 if no complex eigenvalues found.

157. Go to DMAP No. 163 if no output request for the extra points introduced for dynamic analysis or modal coordinates.

158. VDR prepares eigenvectors for output, using only the extra points introduced for dynamic analysis and modal coordinates.

160. Go to DMAP No. 163 if no output request for the extra points introduced for dynamic analysis or modal coordinates.

161. DFP formats eigenvectors for extra points introduced for dynamic analysis and modal coordinates and places them on the system output file for printing.

164. FA2 appends eigenvectors to PHIHL, eigenvalues to CLAMAL, Case Control to CASEYY, and V-g plot data to DVG.

167. Go to DMAP No. 172 if there is insufficient time for another flutter loop.

169. Go to DMAP No. 172 if flutter loop complete.

171. Go to DMAP No. 207 for additional aerodynamic configuration triplet values.

175. Go to DMAP No. 179 if no X-Y plot package is present.

176. XYTRAN prepares the input for requested X-Y plots.

178. XYPLDT prepares requested X-Y plots of displacements, velocities, accelerations, forces, stresses, loads or single-point forces of constraint vs. time.

181. Go to DMAP No. 215 if no output requests involve dependent degrees of freedom or forces and stresses.

182. MODACC selects a list of eigenvalues and vectors whose imaginary parts (velocity in input units) are close to a user input list.

183. DDR1 transforms the complex eigenvectors from modal to physical coordinates

$$[\phi_d^c] = [\phi_{dh}] [\phi_h] .$$

185. Equivalence $[\phi_p^c]$ to $[\phi_p^c]$ if no constraints applied.

186. Go to DMAP No. 188 if no constraints applied.

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187. SDR1 recovers dependent components of eigenvectors

$$(\phi_d^c) = [G_o^d](\phi_d^c) , \quad \begin{Bmatrix} \phi_d^c \\ \phi_o^- \end{Bmatrix} = (\phi_f^c + \phi_e^c) .$$

$$\begin{Bmatrix} \phi_f^c + \phi_e^c \\ \phi_s^c \end{Bmatrix} = (\phi_n^c + \phi_e^c) , \quad (\phi_m^c) = [G_m^d](\phi_n^c + \phi_e^c) .$$

$$\begin{Bmatrix} \phi_f^c + \phi_e^c \\ \phi_e^c \end{Bmatrix} = (\phi_p^c)$$

and recovers single-point forces of constraint $(q_s) =$

$$[K_{fs}^T](\phi_f) , \quad \begin{Bmatrix} \phi_o^- \\ q_s \end{Bmatrix} = (Q_p^c) .$$

190. Equivalence $[\phi_d^c]$ to $[\phi_a^c]$ if no extra points introduced for dynamic analysis.
191. Go to DMAP No. 194 if no extra points present.
192. VEC generates a d-size partitioning vector (RP) for the a and e sets.
193. PARTN performs partition of $[\phi_d^c]$ using RP.

$$(\phi_d^c) = \begin{Bmatrix} \phi_a^c \\ \frac{\phi_c}{\phi_e^c} \end{Bmatrix}$$

195. SDR2 calculates element forces and stresses ($\theta EFC1$, $\theta ESC1$) and prepares eigenvectors and single-point forces of constraint for output ($\theta CPHIP$, $\theta QPC1$). It also prepares PCPHIP for deformed plotting.
197. θFP formats tables prepared by SDR2 and places them on the system output file for printing.
198. Go to DMAP No. 194 if no deformed structure plots are requested.
199. PL0T prepares all deformed structure plots.
200. PRTMSG prints plotter data and engineering data for each deformed plot generated.
202. Go to DMAP No. 215 and make normal exit.
204. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 1 - MASS MATRIX REQUIRED FOR MODAL FORMULATION.
206. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FOR REAL EIGENVALUE ANALYSIS.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

- 208. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 3 - ATTEMPT TO EXECUTE MORE THAN 100 LOOPS.
- 210. MODAL COMPLEX EIGENVALUE ANALYSIS ERROR MESSAGE NO. 4 - REAL EIGENVALUES REQUIRED FOR MODAL FORMULATION.
- 212. NORMAL MODES WITH CYCLIC SYMMETRY ERROR MESSAGE NO. 4 - FREE BODY SUPPORTS NOT ALLOWED.
- 214. NORMAL MODES WITH CYCLIC SYMMETRY ERROR MESSAGE NO. 5 - CYCLIC SYMMETRY DATA ERROR.

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3.23.3 Output for Compressor Blade Modal Flutter Analysis

The Real Eigen value Summary Table and the Real Eigenvalue Analysis summary, as described under Normal Mode Analysis, are automatically printed. All real eigenvalues are included even though all may not be used in the modal formulation.

The grid point singularities from the structural model are also output.

A flutter summary for each value of the configuration parameters is printed out if PRINT=YESB. This shows ρ , k , $1/k$, σ , σ^*V_{sound} , V , g and f for each complex eigenvalue.

$V-g$ and $V-f$ plots may be requested by the XYAUT control cards by specifying the curve type as VG. The "points" are loop numbers and the "components" are G or F.

Printed output of the following types, sorted by complex eigenvalue root number (SORT1) and (m , k , ρ) may be requested for all complex eigenvalues kept, as either real and imaginary parts or magnitude and phase angle (0° - 360° lead):

1. The eigenvector for a list of PHYSICAL points (grid points, extra points) or SOLUTION points (modal coordinates and extra points).
2. Nonzero components of the single-point forces of constraint for a list of PHYSICAL points.
3. Complex stresses and forces in selected elements.

The @FREQUENCY case control card can select a subset of the complex eigenvectors for data recovery. In addition, undeformed and deformed shapes may be requested. Undeformed shapes may include only structural elements.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

3.23.4 Case Control Deck and Parameters for Compressor Blade Cyclic Modal Flutter Analysis

1. Only one subcase is allowed
2. Desired direct input matrices for stiffness [K^2_{pp}], mass [M^2_{pp}], and damping [B^2_{pp}] must be selected via the keywords K2PP, M2PP, or B2PP.
3. CMETHOD must be used to select an EIGC card from the Bulk Data Deck.
4. FMETHOD must be used to select a FLUTTER card from the Bulk Data Deck.
5. METHOD must be used to select an EIGR card that exists in the Bulk Data Deck.
6. SDAMPING must be used to select a TABDMPI table if structural damping is desired.
7. An SPC set must be selected unless the model is a free body or all constraints are specified on GRID cards, Scalar Connection Cards or with General Elements.
8. Each NASTRAN run calculates modes for only one symmetry index, K.

The following user parameters are used in Compressor Blade Cyclic Modal Flutter Analysis.

1. GRDPNT - optional - A positive integer value of this parameter will cause the Grid Point Weight Generator to be executed and the resulting weight and balance information to be printed. All fluid related masses are ignored.
2. WTMASS - optional - The terms of the structural mass matrix are multiplied by the real value of this parameter when they are generated in SMA2. Not recommended for use in hydroelastic problems.
3. COPUMASS, CPBAR, CPRD, CPOUAD1, CPOUAD2, CPTRIA1, CPTRIA2, CPTUBE, CPODPLT, CPTRPLT, CPTRBSC - optional - These parameters will cause the generation of coupled mass matrices rather than lumped mass matrices for all bar elements, rod elements, and plate elements that include bending stiffness.

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4. LFREQ and HFREQ - required unless LM0DES is used. The real values of these parameters give the frequency range (LFREQ is lower limit and HFREQ is upper limit) of the modes to be used in the modal formulation. To use this option, LM0DES must be set to 0.
5. LM0DES - used unless set to 0. The integer value of this parameter is the number of lowest modes to be used in the modal formulation. The default value will request all modes to be used.
6. N0DJE - optional in modal flutter analysis. A positive integer of this parameter indicates that user supplied downwash matrices due to extra points are to be read from tape via the INPUTT2 module in the rigid format. The default value is -1.
7. P1, P2 and P3 - required in modal flutter analysis when using N0DJE parameter. See Section 5.3.2 for tape operation parameters required by INPUTT2 module. The defaults for P1, P2, and P3 are -1, 11 and TAPEID, respectively.
8. VREF - optional in modal flutter analysis. Velocities are divided by the real value of this parameter to convert units or to compute flutter indices. The default value is 1.0.
9. PRINT - optional in modal flutter analysis. The BCD value N0, of this parameter will suppress the automatic printing of the flutter summary for the k method. The flutter summary table will be printed if the BCD value is YES for wing flutter, or YESB for blade flutter. The default is YES.
10. CTYPE - required - the BCD value of this parameter defines the type of cyclic symmetry as follows:
 - (1) ROT - rotational symmetry
 - (2) DRL - dihedral symmetry, using right and left halves
 - (3) DSA - dihedral symmetry, using symmetric and anti-symmetric components
11. NSEGS - required - the integer value of this parameter is the number of identical segments in the structural model.

COMPRESSOR BLADE CYCLIC MODAL FLUTTER ANALYSIS

12. CYCSEQ - optional - the integer value of this parameter specifies the procedure for sequencing the equations in the solution set. A value of +1 specifies that all cosine terms should be sequenced before all sine terms, and a value of -1 for alternating the cosine and sine terms. The default value is -1.
13. KINDEX - required in compressor blade cyclic modal flutter analysis. The integer value of this parameter specifies a single value of the harmonic index.
14. MINMACH - optional in blade flutter analysis. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid. The default is 1.01.
15. MAXMACH - optional in blade flutter analysis. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid. The default value is 0.80.
16. IREF - optional in blade flutter analysis. This defines the reference streamline number. IREF must be equal to a SLN on a STREAML2 bulk data card. The default value, -1, represents the streamsurface at the blade tip. If IREF does not correspond to a SLN, then the default will be taken.
17. MTYPE - optional in cyclic modal blade flutter analysis. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = COSINE for cosine components. The default BCD value is COSINE.
18. KGGIN - optional in blade flutter analysis. A positive integer of this parameter indicates that the user supplied stiffness matrix is to be read from tape (GINO file INPT) via the INPUT1 module in the rigid format. The default is -1.

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149 FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149.1 Entry Point: UDO300

4.149.2 Purpose

The principal function of ALG is to generate an aerodynamic pressure and/or temperature distribution for compressor blades. The ALG module may also be used as a compressor blade mesh generator to punch GRID, CTRIA2 and PTRIA2 bulk data cards. Bulk data cards STREAML1 and STREAML2 can also be generated by ALG by user request.

4.149.3 DMAP Calling Sequence

```
ALG CASECC, EDT, EQEXIN, {AUGVUBGV}, ALGDB, CSTM, BGPDT/ CASECCA, GEOM3A/  
S, Y, APRESS/ S, Y, ATEMP/ V, Y, STREAML/ V, Y, PGEOM/ V, Y, IPRT/  
S, N, IFAIL/ V, Y, SIGN/ V, Y, ZORIGN/ V, Y, FXC0R/ V, Y, FYC0R/  
V, Y, FZC0R $
```

4.149.4 Input Data Blocks

CASECC - Case control data table
EDT - Aerodynamic bulk data cards
EQEXIN - Equivalence between external grid or scalar numbers and internal numbers
AUGV } - Displacement vector matrix giving displacements in the g-set
UBGV
ALGDB - Compressor blade data table
CSTM - Coordinate system transformation matrices
BGPDT - Basic grid point definition table

Notes:

1. CASECC and ALGDB cannot be purged.
2. AUGV or UBGV can be purged.

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

3. EQEXIN, CSTM and BGPDT can be purged if AUGV is purged.
4. EDT can be purged if AUGV is purged and parameter STREAML = -1.
5. ALGDB may be input via DTI bulk data cards.

4.149.5 Output Data Blocks

CASECCA - Revised case control data table

GEOM3A - Static load and temperature table

Note:

1. CASECCA and GEOM3A may not be purged.

4.149.6 Parameters

APRESS - Input - integer - default = -1. If APRESS > 0, then aerodynamic pressures will be generated.

ATEMP - Input - integer - default = -1. If ATEMP > 0, then aerodynamic temperatures will be generated.

STREAML - Input - integer - default = -1. Controls the punching of STREAML1 and STREAML2 cards. STREAML = 1, punch STREAML1 cards. STREAML = 2, punch STREAML2 cards. STREAML = 3, punch both STREAML1 and STREAML2 cards.

PGEOM - Input - integer - default = -1. Controls the punching of blade geometry bulk data cards. PGEOM = 1, punch GRID cards. PGEOM = 2, punch GRID, CTRIA2 and PTRIA2 cards. PGEOM = 3, punch GRID cards and the modified ALGDB table on DTI cards.

IPRT - Input - integer - default = 0. If IPRT > 0, then intermediate print will be generated based on the print option in ALGDB data table.

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

IFAIL - Output - integer - default = 0. Set to -1 if there is a convergence failure.

SIGN - Input - real - default = 1.0. Controls the type of analysis being performed. SIGN = 1.0 for standard blade analysis.
SIGN = -1.0 for design analysis.

ZORIGN - Input - real - default = 0.0. Modification factor.

FXC00R - Input - real - default = 1.0. Modification factor.

FYC00R - Input - real - default = 1.0. Modification factor.

FZC00R - Input - real - default = 1.0. Modification factor.

4.149.7 Method

- (a) Data block ALGDB contains all the input needed to generate the aerodynamic pressures and temperatures on the compressor blade. However, the aerodynamic loads are a function of the blade shape and the data defined in ALGDB must first be modified to account for any change in the blade shape or input via the displacement vector matrix AUGV. If AUGV is purged, then ALGDB is not modified. The ALGDB data block is read and the aerodynamic loads are calculated for the compressor blade being analyzed.
- (b) The CASECC data block is read and a copy of it is output to CASECCA with changes to data items 4 and 7 for all subcases. In CASECCA, word 4 is set to 60 if aerodynamic pressure loads were generated, and word 7 is set to 70 if aerodynamic thermal loads were generated.
- (c) The GE0M3A data block contains aerodynamic load and temperature data. If parameter APRESS > 0, then PL0AD2 cards with set identification number 60 are stored on GE0M3A. If parameter ATEMP > 0, then TEMP and TEMPD cards with set identification number 70 are stored on GE0M3A

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

- (d) Parameters STREAML and PCGM control the punching of bulk data cards STREAML1, STREAML2, GRID, CTRIA2, PTRIA2 and DTI. The ALG module may be used in a one module DMAP program as a compressor blade mesh and geometry generator as follows:

```
BEGIN $  
ALG CASECC,,,ALGDB,,/CASECCA,GE0M3A/C,N,-1/C,N,-1/C,N,3/C,N,2/C,N,1$  
END $
```

4.149.8 Subroutines Called

4.149.8.1 Utility subroutines GMMATS, PRETRS and TRANSS are called.

4.149.8.2 Subroutine Name: UDO3PR

1. Entry Point: UDO3PR
2. Purpose: Modify ALGDB data block.
3. Calling Sequence: CALL UDO3PR (IERR)

4.149.8.3 Subroutine Name: UDO3PB

1. Entry Point: UDO3PB
2. Purpose: Identify data fields as being either BCD alpha, real or integer.
3. Calling Sequence: CALL UDO3PB (IDAT, NTYPE)

4.149.8.4 Subroutine Name: UDO3P0

1. Entry Point: UDO3P0
2. Purpose: Generate data blocks CASECCA and GE0M3A.
3. Calling Sequence: CALL UDO3P0 (SCR1)

4.149.8.5 Subroutine Name: UDO3AP

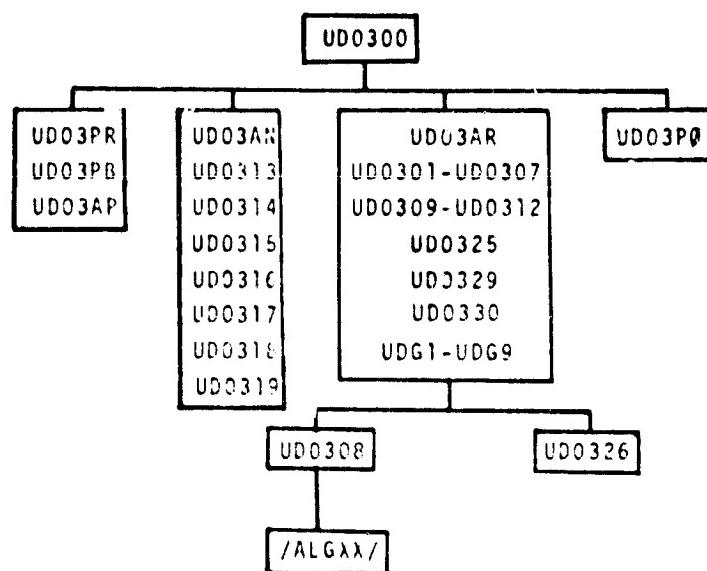
- 1. Entry Point: UDO3AP**
- 2. Purpose: Punch the modified ALGDB table data block on DTI Bulk Data cards if parameter PGEOF = 3.**
- 3. Calling Sequence: CALL UDO3AP (IFNAME, IFNM)**

FUNCTIONAL MODULE ALG (AERODYNAMIC LOAD GENERATOR)

4.149.8.6 Subroutines: UD03AN, UD03AR, UD03C1-UD0319, UD0325, UD0326, UD0329, UD0330 and UDG1-UDG9 are described in references ARL-72-0171, AD-756879; and ARL-75-0001, AD-A009273.

4.149.9 Design Requirements

1. ALG uses 4 scratch files.
2. Overlay considerations - to maximize open core, ALG could look as follows:



4.149.10 Diagnostic Messages

The following messages may occur: 3001, 3002, 3003 and 3008.

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

4.150 FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

4.150.1 Entry Point: APDB

4.150.2 Purpose

Bulk data cards which control the solution of aerodynamic problems are processed and assembled into various blocks for convenience and efficiency in the solution of the aerodynamic problem. APDB also generates the transformation matrix $[G_{ka}]^T$ (GTKA) and the partitioning vector PVECT.

4.150.3 DMAP Calling Sequence

```
APDB    EDT, USET, BGPDT, CSTM, EQEXIN, GM, G0/ AERO, ACPT, FLIST, GTK,
        PVECT/ V, N, NK/ V, N, NJ/ V, Y, MINMACH/ V, Y, MAXMACH/ V, Y, IREF/
        V, Y, MTYPE/ V, N, NEIGV/ V, Y, KINDEX = -1 $
```

4.150.4 Input Data Blocks

EDT - Aerodynamic bulk data cards

USET - Displacement set definition table

BGPDT - Basic grid point definition table

CSYM - Coordinate system transformation matrices

EQEXIN - Equivalence between external points and scalar index values

GM - Multipoint constraint transformation matrix

G0 - Structural matrix partitioning transformation matrix

Notes:

1. EDT, USET, BGPDT and EQEXIN cannot be purged.

2. CSTM may be purged if all points are in the basic system.

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

3. GM and G0 may be purged if there are no multipoint or no omitted points.

4.150.5 Output Data Blocks

AERO - Control information for control of aerodynamic matrix generation and flutter analysis

ACPT - Information pertaining to each independent group of aerodynamic elements

FLIST - Contains AERO, FLCFACT and FLUTTER cards copied from EDT

GTKA - Aerodynamic transformation matrix - K set to a set

PVECT - Cyclic modes partitioning vector for matrix PHIA from module CYCT2

Notes:

1. AERO, ACPT, FLIST and GTKA cannot be purged.

2. PVECT may be purged if there are no cyclic modes to be partitioned.

4.150.6 Parameters

NK - Output - integer - no default. Degrees of freedom in the NK displacement set.

NJ - Output - integer - no default. Degrees of freedom in the NJ displacement set.

MINMACH - Input - real - default = 0.8. This is the maximum Mach number below which the subsonic unsteady cascade theory is valid.

MAXMACH - Input - real - default = 1.01. This is the minimum Mach number above which the supersonic unsteady cascade theory is valid.

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

- IREF - Input - integer - default = -1. This defines the streamline number of the reference stream surface. IREF must equal an SLN on a STREAML2 card. The default value, -1, represents the stream surface at the blade tip. If IREF does not correspond to an SLN, then the default will be taken.
- MTYPE - Input - BCD - default = COSINE. This controls which components of the cyclic modes are to be used in the modal formulation. MTYPE = SINE for sine components and MTYPE = COSINE for cosine components.
- NEIGV - Input - BCD - no default. The number of eigenvalues found. Usually output by the READ module.
- KINDEX - Input - BCD - default = -1. Harmonic index number used in cyclic analyses.

4.150.7 Method

Subroutine APDB is the main control program for this module. It allocates buffers, reads input files, and initializes output files. APDB creates the AERO, ACPT and FLIST tables and generates the PVECT partitioning vector. Subroutine APDB1 generates the GTKA transformation matrix. APDB1 reduces $[G_{Kg}^T]$ to $[G_{Ka}^T]$, much like module SSG2, using the following matrix operations:

$$[G_{Kg}^T] \rightarrow \begin{bmatrix} G_{KN}^T \\ \hline G_{KM}^T \end{bmatrix}$$

$$[G_{KN}^T] = [G_M^T]^T [G_{KM}^T] + [G_{KN}^T]$$

$$[G_{KN}^T] \rightarrow \begin{bmatrix} G_{Kf}^T \\ \hline G_{KS}^T \end{bmatrix}$$

FUNCTIONAL MODULE APDB (AERODYNAMIC POOL DISTRIBUTOR FOR BLADES)

$$[G_{Kf}^T] = \begin{bmatrix} G_{K\theta}^T \\ G_{K\phi}^T \end{bmatrix}$$

$$[G_{Ka}^T] = [G_\theta]^T [G_{K\theta}^T] + [G_{K\phi}^T]$$

At each step where a matrix multiply is indicated, the multiply is skipped if the result is known to be zero (i.e., U_h or U_g are null).

4.150.8 Subroutines Called

Utility routines BISL0C, CALCV, SSG2B, TRANSS and GMMATS all called.

4.150.8.1 Subroutine Name: APDB1

1. Entry Point: APDB1
2. Purpose: To generate transformation matrix $[G_{Ka}^T]$.
3. Calling Sequence: CALL APDB1 (IBUF1, IBUF2, NEXT, LEFT, NSTNS, NLINE\$, LCSTM, ACSTM, N0DEX, N0DEI, I8ILC, XYZB).

4.150.9 Design Requirements

Open core is located at /APDB2Z/. APDB uses five scratch files.

4.150.10 Diagnostic Messages

System fatal messages 3001, 3002, 3003, 3008 and 3037 may occur. The APDB module also generates its own messages that are not numbered. These messages are self-explanatory.

RIGID FORMAT DIAGNOSTIC MESSAGES

6.1.1.16 Rigid Format Error Messages for Static Aerothermoelastic Analysis with Differential Stiffness

HB. 1 - NO STRUCTURAL ELEMENTS HAVE BEEN DEFINED.

The differential stiffness matrix is null because no structural elements have been defined with Connection cards.

HB. 2 - FREE BODY SUPPORTS NOT ALLOWED.

Free bodies are not allowed in Static Analysis with Differential Stiffness. The SUPPORT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

HB. 3 - MASS MATRIX REQUIRED FOR WEIGHT AND BALANCE CALCULATIONS.

The mass matrix is null because either no elements were defined with Connection cards, nonstructural mass was not defined on a Property card, or the density was not defined on a Material card.

HB. 5 - NO INDEPENDENT DEGREES OF FREEDOM HAVE BEEN DEFINED.

Either no degrees of freedom have been defined on GRID, SPINIT or Scalar Connection cards, or all defined degrees of freedom have been constrained by SPC, MPC, DMIT, or GROSET cards, or grounded on Scalar Connection cards.

RIGID FORMAT DIAGNOSTIC MESSAGES

6.1.3 Aero Approach Rigid Formats

The texts of the rigid format error messages are given in the following section for the aero approach rigid formats. The text for each message is given in capital letters and is followed by additional explanatory material, including suggestions for remedial action.

6.1.3.1 Rigid Format Error Messages for Modal Flutter Analysis

NØ. 1 - MASS MATRIX REQUIRED FØR MØDAL FØRMULATØRN.

- The mass matrix is null because either no structural elements were defined with Connection cards, nonstructural mass was not defined on a Property card or the density was not defined on a Material card.

NØ. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FØR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHOD must select an EIGR set in the Case Control Deck.

NØ. 3 - ATTEMPT TØ EXECUTE MØRE THAN 100 LØØPS.

An attempt has been made to use more than 100 different sets of direct input matrices. This number can be increased by altering the REPT instruction following FA2.

NØ. 4 - REAL EIGENVALUES REQUIRED FØR MØDAL FØRMULATØRN.

No real eigenvalues were found in the frequency range specified by the user.

6.1.3.2 Rigid Format Error Messages for Compressor Blade Cyclic Modal Flutter Analysis.

NØ. 1 - MASS MATRIX REQUIRED FØR MØDAL FØRMULATØRN

The mass matrix is null because either no structural elements were defined with Connection cards, nonstructural mass was not defined on a Property card or the density was not defined on a Material card.

NØ. 2 - EIGENVALUE EXTRACTION DATA REQUIRED FØR REAL EIGENVALUE ANALYSIS

Eigenvalue extraction data must be supplied on an EIGR card and METHOD must select an EIGR set in the Case Control Deck.

NØ. 3 - ATTEMPT TØ EXECUTE MØRE THAN 100 LØØPS.

An attempt has been made to use more than 100 different sets of direct input matrices. This number can be increased by altering the REPT instruction following FA2.

NØ. 4 - REAL EIGENVALUES REQUIRED FØR MØDAL FØRMULATØRN.

No real eigenvalues were found in the frequency range specified by the user.

NO. 5 - FREE BODY SUPPORTS NOT ALLOWED.

Free bodies are not allowed in Statics with Cyclic Symmetry. The SUPPORT cards must be removed from the Bulk Data Deck and other constraints applied if required for stability.

NO. 6 - CYCLIC SYMMETRY DATA ERROR.

See Section 1.12 for proper modeling techniques and corresponding PARAM card requirements.

NASTRAN DICTIONARY

A	P	Parameter value used to control utility module MATGPR print of A-set matrices.
ABFL	DBM	[A _{b,f₁}] = Hydroelastic boundary area factor matrix.
ABFLT	DBM	Transpose of [A _{b,f₁}]
ACCE	IC	Abbreviated form of ACCELERATION.
ACCELERATION	IC	Output request for acceleration vector. (UM-2.3, 4.2)
ACPT	DBT	Aerodynamic Connection and Property Data.
Active Column	PH	Column containing at least one nonzero term outside the band.
ADD	FMM	Functional module to add two matrices together.
ADD	M	Parameter constant s d in utility module PARAM.
ADD5	FMM	Functional Module to add up to five matrices together.
ADUMI	IB	Defines attributes of dummy elements 1 through 9.
AEFACT	IB	Used to input lists of real numbers for aeroelastic analysis.
AERO	DBT	Aerodynamic Matrix Generation Data.
AERO	IB	Gives basic aerodynamic parameters.
AJL	DBML	Aerodynamic Influence Matrix List.
ALG	FMS	Aerodynamic load generator.
ALGDB	DBT	Aerodynamic Load input for ALG (D-16).
ALL	IC	Output request for all of a specified type of output.
ALLEdge TICS	IC	Request tic marks on all edges of X-Y plot.
ALOAD	P	Set negative if no aerodynamic loads (D-16).
ALTER	IA	Alter statement for DMAP or rigid format.
ALWAYS	P	Parameter set to -1 by a PARAM statement in the Piecewise Linear Analysis Rigid Format (D-6).
AMG	FMS	Aerodynamic Matrix Generator
AMP	FMS	Aerodynamic Matrix Processor.
AND	M	Parameter constant used in executive module PARAM.
AOUT\$	M	Indicates restart with solution set output request.
APD	FMS	Aerodynamic pool distributor and element generator.

NASTRAN DICTIONARY

APDB	FMS	Aerodynamic pool distributor for blades.
APP	IA	Control card which specifies approach (DISP or DMAP).
APPEND	M	File may be extended (see FILE).
APRESS	PU	Positive Value generates aerodynamic pressures.
ASET	IB	Analysis set coordinate definition card.
ASET1	IB	Analysis set coordinate definition card
ATEMP	PU	Positive value generates aerodynamic temperatures.
AUTO	IC	Requests X-Y plot of autocorrelation function.
AUTO	DBT	Autocorrelation function table.

NASTRAN DICTIONARY

CQDMEM2	IB	Quadrilateral membrane element connection definition card.
CQDPLT	IB	Quadrilateral bending element connection definition card.
CQUAD1	IB	General Quadrilateral element connection definition card.
CQUAD2	IB	Homogeneous quadrilateral element connection definition card.
CRD	IB	Rod element connection definition card.
CSHEAR	IB	Shear panel element connection definition card.
CSLT3	IB	Triangular slot element connection definition card for acoustic analysis.
CSLT4	IB	Quadrilateral slot element connection definition card for acoustic analysis.
CSP	IC	Selects a set of contact surface points.
CSP	IB	Contact surface point set definition.
CSTM	DBT	Coordinate System Transformation Matrices.
CSTM	DBT	Coordinate System Transformation Matrices - Aerodynamics.
CTETRA	IB	Tetrahedron element connection definition card.
CTRDRG	IB	Toroidal ring element connection card.
CTRPRG	IB	Trapezoidal ring element connection card.
CTRBS	IB	Basic bending triangular element connection definition card.
CTRIAI	IB	General triangular element connection definition card.
CTRIA2	IB	Homogeneous triangular element connection definition card.
CTRIARG	IB	Triangular ring element connection card.
CTRMEM	IB	Triangular membrane element connection definition card.
CTRPLT	IB	Triangular bending element connection definition card.
CTUBE	IB	Tube element connection definition card.
CTWIST	IB	Twist panel element connection definition card.
CURLINESYMBOL	IC	Request to connect points with lines and/or to use symbols for X-Y plots.
CVISC	IB	Viscous damper element connection definition card.
CWEDGE	I3	Wedge element connection definition card.

NASTRAN DICTIONARY

FORCE2	IB	Static load definition (magnitude and four grid points).
FORCEAX	IB	Static load definition for conical shell problem.
FREEPT	IB	Defines point on a free surface of a fluid for output purposes.
FREQ	IB	Frequency list definition.
FREQ\$	M	Indicates restart with change in frequencies to be solved.
FREQ1	IB	Frequency list definition (linear increments).
FREQ2	IB	Frequency list definition (logarithmic increments).
FREQRESP	P	Parameter used in SDR2 to indicate a frequency response problem.
FREQUENCY	IC	Selects the set of frequencies to be solved in frequency response problems.
FRL	DBT	Frequency Response List.
FRQSET	P	Used in FRRD to indicate user selected frequency set.
FRRD	FMS	Frequency and Random Response - Displacement approach.
FSAVE	DBT	Flutter Storage Save Table.
FSLIST	IB	Defines a free surface of a fluid in a hydroelastic problem.
Functional Module	PH	An independent group of subroutines that perform a structural analysis function.
FXCOOR	PU	Aerodynamic modification factor (D-16).
FYCOOR	PU	Aerodynamic modification factor (D-16).
FZCOOR	PU	Aerodynamic modification factor (D-16).

IC	IC	Transient analysis initial condition set selection.
ID	IA	The first card of any data deck is the identification (ID) card. The two data items on this card are RCD values.
IFAIL	P	Set negative by ALG if convergence fails (D-16).
IFP	EM	Input File Processor. The preface module which processes the sorted Bulk Data Deck and outputs various data blocks depending on the card types present in the Bulk Data Deck.
IFP1	EM	Input File Processor 1. The preface module which processes the Case Control Deck and writes the CASECC, PCDB and XYCDB data blocks.
IFP3	EM	Input File Processor 3. The preface module which processes bulk data cards for a conical shell problem.
IFP4	EM	Input File Processor 4. The preface module which processes bulk data cards for a hydroelastic problem.
IMAG	IC	Output request for real and imaginary parts of some quantity such as displacement, load, single point force of constraint element force, or stress.
IMPL	P	Parameter constant used in executive module PARAM.
INCLUDE	IC	Used in set definition for structure plots.
INERTIA	P	Used in printing rigid format error messages for Static Analysis with Inertia Relief (D-2).
INERTIA RELIEF	IA	Selects rigid format for static analysis with inertia relief.
INPT	M	A reserved NASTRAN physical unit (Tape) which must be set up by the user when used.
INPUT	FMU	Generates most of bulk data for selected academic problems.
Input Data Block	PH	A data block input to a module. An input data block must have been previously output from some module and may not be written on.
Input Data Cards	PH	The card input data to the NASTRAN system are in 3 sets, the Executive Control Deck, the Case Control Deck, and the Bulk Data Deck.
INPUT1	FMU	Reads data blocks from GINO-written user tapes.
INPUT2	FMU	Reads data blocks from FORTRAN-written user tapes.
INPUT3	FMX	Dummy user input module.
INPUT4	FMX	Dummy user input module.
Internal Sort	PH	Same order as external sort except when SEQGP or SEQEP bulk data cards are used to change the sequence.
INV	IB	Inverse power eigenvalue analysis option - specified on EIGR, EIGB or EIGC cards.
IPRT	PU	Controls printing of aerodynamic results.
IREF	PU	Defines reference streamline for blade flutter.
IRES	P	Causes printout of residual vectors in statics rigid formats when set nonnegative via a PARAM bulk data card. (D-1, D-2, D-4, D-5, D-6).

NASTRAN DICTIONARY

KDSS	DBM	$[K_{ss}^d]$ - Partition of differential stiffness matrix.
KFF	DBM	$[K_{ff}]$ - Partition of stiffness matrix.
KFS	DBM	$[K_{fs}]$ - Partition of stiffness matrix.
KGG	DBM	$[K_{gg}]$ - Stiffness matrix generated by Structural Matrix Assembler.
KGGIN	PU	Positive value selects KGGX from INPUT1.
KGGIN	DBM	Sum of elastic and differential stiffness matrices (D-16, A-9).
KGGL	DBM	$[K_{gg}^L]$ - Stiffness matrix for linear elements. Used only in the Piecewise Linear Analysis Rigid Format (D-6).
KGGLPG	P	Purge flag for KGGL matrix. If set to -1, it implies that there are no linear elements in the structural model. (D-6).
KGGNL	DBM	$[K_{gg}^{NL}]$ - Stiffness matrix for the nonlinear elements. Used in the Piecewise Linear Analysis Rigid Format only. (D-6).
KGGSUM	DBM	Sum of KGGNL and KGGL. Used in the Piecewise Linear Analysis Rigid Format only. (D-6).
KGGX	DBM	$[K_{gg}^X]$ - Stiffness matrix excluding general elements.
KGGXL	DBM	$[K_{gg}^{XL}]$ - Stiffness matrix for linear elements (excluding general elements). Used in the Piecewise Linear Rigid Format only. (D-6).
KHH	DBM	$[K_{hh}]$ - Stiffness matrix used in modal formulation of dynamics problems (D-10 thru D-12).
KLL	DBM	$[K_{ll}]$ - Stiffness matrix used in solution of problems in static analysis (D-1, D-2, D-4, D-5, D-6).
KLR	DBM	$[K_{lr}]$ - Partition of stiffness matrix.
KNN	DBM	$[K_{nn}]$ - Partition of stiffness matrix.
KOO	DBM	$[K_{oo}]$ - Partition of stiffness matrix.
KRR	DBM	$[K_{rr}]$ - Partition of stiffness matrix.
KSS	DBM	$[K_{ss}]$ - Partition of stiffness matrix.
KTOTAL	DBM	Sum of elastic and differential stiffness matrices (D-16, A-9).
KTOUT	PU	Positive value outputs KTOTAL to OUTPUT1.
KXHH	DBM	Total modal stiffness matrix - h-set.

NASTRAN DICTIONARY

MATTS	IB	Specifies table references for temperature-dependent, anisotropic, thermal material properties.
MAX	IB	Eigenvector normalization option - used on EIGR, EIGB and EIGC cards.
MAXIMUM DEFORMATION	IC	Indicates scale for deformed structure plots.
MAXIT	P	Limits maximum number of iterations in nonlinear heat transfer analysis.
MAXLINES	IC	Maximum printer output line count - default value is 20000.
MAXMACH	PU	Controls supersonic unsteady cascade calculations.
MCE1	FMS	Multipoint Constraint Eliminator - part 1.
MCE2	FMS	Multipoint Constraint Eliminator - part 2.
MDD	DBM	$[M_{dd}]$ - Mass matrix used in direct formulation of dynamics problems (D-7 thru D-9).
MDEMA	P	Parameter indicating equivalence of MDD and MAA.
MDLCRAD	P	Used in printing rigid format error messages for modal complex eigenvalue analysis (D-10).
MDLFRRD	P	Used in printing rigid format error messages for modal frequency response (D-11).
MDLTRD	P	Used in printing rigid format error messages for modal transient response (D-12).
MERGE	FMM	Matrix merge functional module.
METHOD	IC	Selects method for real eigenvalue analysis.
METHOD\$	M	Indicates restart with change in eigenvalue extraction procedures.
MFF	DBM	$[M_{ff}]$ - Partition of mass matrix.
MGG	DBM	$[M_{gg}]$ - Mass matrix generated by Structural Matrix Assembler.
MHH	DBM	$[M_{hh}]$ - Mass matrix used in modal formulation of dynamics problems (D-10 thru D-12).
MI	DBM	$[m]$ - Modal mass matrix.
MINMACH	PU	Controls supersonic unsteady cascade calculations.
MKAER01	IB	Provides table of Mach numbers and reduced frequencies (k).
MKAER02	IB	Provides list of Mach numbers (m) and reduced frequencies (k).
MLL	DBM	$[M_{ll}]$ - Partition of mass matrix.
MLR	DBM	$[M_{lr}]$ - Partition of mass matrix.
MNN	DBM	$[M_{nn}]$ - Partition of mass matrix.
MDA	DBM	$[\bar{M}_{oa}]$ - Partition of mass matrix.
MODA	FMX	This module is reserved for user implementation.
MODACC	FMS	Mode Acceleration Output Reduction Module.
MTYPE	PU	Controls cyclic mode component selection.

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P	P	Parameter value used in MATGPR to print P-set matrices.
Packed Format	PM	A matrix is said to be in packed format if only the nonzero elements of the matrix are written.
PAPER SIZE	IC	Selects paper size for structure plots using table plotters.
PARAM	FNU	Performs specified operations on DMAP parameters.
PARAM	IB	Parameter definition card.
Parameter	PH	A FORTRAN variable communicated to a DMAP module by the NASTRAN Executive System through blank common. A parameter's position in the DMAP calling sequence to a module corresponds to the position of the parameter in blank common at module execution time.
PARAML	FNU	Selects parameters from a user input matrix or table.
PARAMR	FNU	Performs specified operations on real or complex parameters.
PARTN	FMM	Matrix partitioning functional module.
PBAR	IB	Bar property definition card.
PBL	DBM	A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).
PBS	DBM	A scalar multiple of the PL load vector. Used only in the Differential Stiffness Rigid Format (D-4).
PCD3	DBT	Plot control data block (table for use with structure plotter functional module PLTSET).
PCONEAX	IB	Conical shell element property definition card.
PDAMP	IB	Scalar damper property definition card.
PDF	DBM	Dynamic load matrix for frequency analysis.
PDT	DBM	Linear dynamic load matrix for transient analysis.
PDUM1	IB	Property definition card for dummy elements 1 through 9.
PELAS	IB	Scalar elastic property definition card.
PEN	IC	Selects pen size for structure plots using table plotters.
PENSIZE	IC	Selects pen size for X-Y plots using table plotters.
PERSPECTIVE	IC	Specifies perspective projection for structure plots.
PFILE	P	Parameter used by PLDT module.
PG	DBM	Incremental load vector used in Piecewise Linear Analysis (D-6).
PG	DBM	Statics load vector generated by SSG1.
PG1	DBM	Static load vector for Piecewise Linear Analysis (D-6).
PGEOM	PU	Controls punching of GRID, CTRIA2, PTRIA2 and DTI cards from ALG.
PGG	DBM	Appended static load vector (D-1, D-2).

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PUGV1	DBT	Displacement components used to plot deformed shape (D-6).
PUNCH	IC	Output media request (PRINT or PUNCH).
PURGE	EM	DMAP statement which causes conditional purging of data blocks.
Purge	PH	A data block is said to be purged when it is flagged in the FIAT so that it will not be allocated to a physical file and so that modules attempting to access it will be signaled.
PVECT	DBM	Partitioning vector for cyclic modes (A-9).
PVISC	IB	Viscous element property definition card.
PVT	PH	Parameter value table. The PVT contains BCD names and values of all parameters input by means of PARAM bulk data cards. It is generated by the preface module IFP and is written on the Problem Tape.
P1	PU	INPUTT2 rewind option.
P2	PU	INPUTT2 unit number.
P3	PU	INPUTT2 tape ID.
QBDY1	IB	Defines uniform heat flux into HBDY elements.
QBDY2	IB	Defines grid point heat flux into HBDY elements.
QBG	DBM	Single point forces of constraint in the Differential Stiffness Rigid Format (D-4).
QDMEM	IC	Requests structure plot for all QDMEM elements.
QDMEM1	IC	Requests structure plot for all QDMEM1 elements.
QDMEM2	IC	Requests structure plot for all QDMEM2 elements.
QDPLT	IC	Requests structure plot for all QDPLT elements.
QG	DBM	Constraint forces for all grid points.
QHBDY	IB	Defines thermal load for steady-state heat conduction.
QHML	DBML	Aerodynamic matrix list - h-set.
QJHL	DBML	Aerodynamic transformation matrix between h and j sets.
QP	DBM	Constraint forces for all physical points.
QPC	DBM	Complex single point forces of constraint for all physical points.
QR	DBM	(q _r) - Determinant support forces.
QS	DBM	(q _s) - Single-point constraint forces.
QUAD1	IC	Requests structure plot for all QUAD1 elements.
QUAD2	IC	Requests structure plot for all QUAD2 elements.
QVECT	IB	Defines thermal vector flux from distant source.
QVOL	IB	Defines volume heat generation.

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SIGA	P	Defines Stefan-Boltzmann constant in heat transfer analysis.
SIGN	PU	Controls the type of static aerothermo-elastic analysis performed.
SIL	DBT	Scalar Index List for all grid points.
| SILA	DBT	Scalar Index List - Aerodynamics.
| SILD	DBT	Scalar Index List for all grid points and extra scalar points introduced for dynamic analysis.
| SILGA	DBT	Scalar Index List - Aerodynamic boxes only.
SINE	IC	Conical shell request for sine set boundary conditions.
SINGLE	P	No single-point constraints.
SKIP BETWEEN FRAMES	IC	Request to insert blank frames on SC 4020 plotter for X-Y plots.
| SKJ	DBM	Integration matrix.
SKPMGG	P	Parameter used in statics to control execution of functional module SMA2.
SLBDY	IB	Defines list of points on interface between axisymmetric fluid and radial slots.
SLBAD	IB	Scalar point load definition.
SLT	DBT	Static Loads Table.
SMA1	FMS	Structural Matrix Assembler - phase 1 - generates stiffness matrix $[K_{gg}]$ and structural damping matrix $[K_{gg}^4]$.
SMA2	FMS	Structural Matrix Assembler - phase 2 - generates mass matrix $[M_{gg}]$ and viscous damping matrix $[B_{gg}]$.
SMA3	FMS	Structural Matrix Assembler - phase 3 - add general element contributions to the stiffness matrix $[K_{gg}]$.
SMP1	FMS	Structural Matrix Partitioner - part 1.
SMP2	FMS	Structural Matrix Partitioner - part 2.
SMPYAD	FMM	Performs multiply-add matrix operation for up to five multiplications and one addition.
SOL	IA	Specifies which rigid format solution is to be used when APP is DISPLACEMENT.
Solution Points	PH	Points used in the formulation of the general K system.
SOLVE	FMM	Solves a set of linear algebraic equations.
SORT1	IC	Output is sorted by frequency or time and then by external ID.
SORT2	IC	Output is sorted by external ID and then by frequency or time.
SORT3	M	Output is sorted by individual item or component and then by frequency or time.
SPC	IB	Single-point constraint and enforced deformation definition.

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SPC	IC	Single-point constraint set selection.
SPCS	M	Indicates restart with change in single-point constraint set selection.
SPC1	IB	Single-point constraint definition.
SPCA00	IB	Single-point constraint set combination definition.
SPCAX	IB	Conical shell single-point constraint definition.
SPCF	IC	Abbreviated form of SPCFORCE.
SPCFORCE	IC	Single-point constraint force output request. (UM-2.3,4.2)
Spill	PH	Secondary storage devices are used because there is insufficient main storage to perform a matrix calculation or a data processing operation.
SPLINE	DBT	Splining Data Table.
SPLINE1	IB	Defines surface spline.
SPLINE2	IB	Defines beam spline.
SPPOINT	IB	Scalar point definition card.
SSG1	FMS	Static Solution Generator - part 1.
SSG2	FMS	Static Solution Generator - part 2.
SSG3	FMS	Static Solution Generator - part 3.
SSG4	FMS	Static Solution Generator - part 4.
SSGHT	FMH	Solution generator for nonlinear heat transfer analysis.
STATIC	IC	Requests deformed structure plot for problem in Static Analysis.
STATICS	IA	Selects statics rigid format for heat transfer or structural analysis.
STATIC\$	P	Parameter used in SDR2 to indicate Static Analysis.
STEADY STATE	IA	Selects rigid format for nonlinear static heat transfer analysis.
STEREOSCOPIC	IC	Requests stereoscopic projections for structure plot.
STREAML	PU	Controls the punching of STREAML1 and STREAML2 cards from ALG.
STREAML1	IB	Gives blade streamline data.
STREAML2	IB	Gives blade streamline data.
STRESS	IC	Element stress output request. (UM-2.3, 4.2)
Structural Element	PH	One of the finite elements used to represent a part of a structure.
SUBCASE	IC	Subcase definition.
SUBCOM	IC	This subcase is a linear combination of previous subcases.
SUBSEQ	IC	Specifies coefficients for SUBCOM subcases.
SUBTITLE	IC	Output labeling data for printer output.
SUPAX	IB	Fictitious support for conical shell problem.

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ZORIGN PU Aerodynamic modification factor (D 16).